BODY MORPHOLOGY AND ILL HEALTH

THANG SIEU HAN

BSc (Honours), Physiology & Sports Science, Glasgow

MSc, Human Nutrition and Metabolism, Aberdeen

A thesis submitted for the degree of Doctor of Philosophy

to

The University of Glasgow

May 1997

From research conducted at the

Department of Human Nutrition, University of Glasgow

Glasgow Royal Infirmary

Glasgow, Scotland

CONTENTS

SUMMARY AND CONCLUSIONS OF THE FINDINGS IN THE PRESENT THESIS

Summary

The present thesis has drawn on a wide range of studies employing a variety of methodologies, aiming to explore the importance of body composition and morphology in relation to health and disease in adults, with a principle consideration of the need for health promotion. To achieve these aims, a series of hypotheses were postulated and a number of research questions were asked, followed by hypothesis testing and data analyses to gain new understanding, and to establish firmly the associations of body morphology with health and disease.

Recognising the limited success in reversing the increasing trends in overweight has prompted the need to design new strategies in promoting public awareness of the risk of ill health associated with overweight and central fat distribution. These studies were carried out in this context to develop simple methods for assessing body composition, to enable health professionals and general public to assess and identify people with increasing health risks associated with overweight and increased intra-abdominal fat accumulation. The use of body mass index is established but is too complex for lay use, and does not take account of fat distribution as an indicator of ill health. Waist circumference was explored since it reflects both fatness and central fat distribution. It was shown that height correlated weakly or not at all with waist circumference. Analysis of magnetic resonance imaging and computerised tomography data showed that height correlated weakly with intra-abdominal fat and had limited influence on the strong relationship between waist circumference and intra-abdominal fat. Thus waist circumference could be used as an index of adiposity and health risk without the need of incorporating height to create complex ratios (height adjustment). New equations employing simple anthropometric variables including a single measurement of waist circumference have been derived and cross-validated in an independent Dutch population. These equations were found to be valid for assessing total body fatness.

Cut-offs of waist circumference were derived to identify people with high body mass index (overweight) or with high waist to hip ratio (central fat distribution): Action Level 1 (94 cm in men, 80 cm in women) identifies those with body mass index above 25 kg/m^2 or waist to hip ratio above 0.95 in men or above 0.80 in women. Action Level 2 (102 cm in men, 88 cm in women) identifies those with body mass index above 30 kg/m^2 or waist to hip ratio above 0.95 in men or above 0.80 in women. Receiver operating characteristic (ROC) analysis showed that Action Level 1 was close to the optimal (at the point where sensitivity equals specificity) value for identifying people with cardiovascular risk factors, including hypertension, hypercholesterolaemia or low high density lipoprotein (HDL) cholesterol.

Excessive accumulation of the metabolically active intra-abdominal fat is associated with metabolic disorders. Magnetic resonance imaging and computerised tomography studies conducted in Aberdeen and The Netherlands have shown that waist circumference is closely related to intra-abdominal fat. Epidemiological studies in the present thesis showed that large waist circumference was associated with poor quality of life and a cluster of metabolic disorders and symptoms of chronic diseases including non-insulin-dependent diabetes mellitus (NIDDM), respiratory symptoms, low back pain, and high blood pressure, high total plasma cholesterol and low HDL cholesterol.

In our cross-sectional study, low hip circumference was related to NIDDM independently of waist (abdominal fat), suggested that reduced muscle mass (i.e. reduced postural, mainly type 1 muscle fibres) may be a consequence of NIDDM.

Analysis of data from a weight reduction follow-up study of free living women showed that moderate reduction (5-10 cm) of waist circumference was associated with 85% chance of improving at least one of the major cardiovascular risk factors in overweight women who had not been selected for high cardiovascular risk.

Features of metabolic syndrome including insulin resistance, NIDDM, Cushing's syndrome, hypertension, and increased intra-abdominal fat accumulation have previously been found to associate with increased type 2b, glycolytic, white muscle fibres. Athletes who specialise in power sports tend to have higher proportions of type 2b muscle fibres than those who specialise in endurance sports who tend to have greater proportion of oxidative, type 1 muscle fibres. A retrospective study of former physical trainees was carried out to test the hypothesis that those with a natural ability in power sports (a presumed marker of type 2 muscle fibre predominance) might have increased risks of cardiovascular disorders compared to those with a natural ability in endurance sports (a marker of type 1 muscle fibre predominance). It was found that compared to men who had a natural ability in endurance sports, those who had a natural ability in power sports were more likely to report the development of cardiovascular disorders.

Epidemiological studies of Barker and colleagues have produced compelling evidence for the associations between small birth weight (presumed to reflect failure in early growth) with health risks through metabolic diseases (coronary heart disease, stroke, non-insulin dependent diabetes mellitus) in later life. The diseases under question are those associated with the 'metabolic syndrome' linked by insulin resistance and with central fat distribution. Our previous studies and that of Law *et al* have found women and men who had small birth weights had increased abdominal fat deposition, indicated by large waist circumference or high waist to hip ratio. Amongst the same women from our previous study, low birth weight also tended to relate to elevated blood pressure and heart rate. The 'thrifty phenotype' and 'programming' hypotheses were assessed as ways to explain possible influences of early nutrition on the development of visceral organ morphology and function to relate to health in later life. It is surprising that little is known about the development and function of the musculoskeletal system, which is the biggest and arguably most expendable organ of all, in relation to metabolic disorders in adulthood. In the present thesis, birth weight was found to correlate negatively with cardiovascular disorders and had an additive effect with natural ability in power sports. Compared to men who had a natural ability in endurance sports and above median birth weight, those with a natural ability in power sports and below median birth weight were more likely to develop CHD and/or risk factors (age, current body mass index, and lifestyle factors adjusted odds ratio = 10.5, 95% confidence interval: 1.9 to 59.5), compared to men in the endurance group with above median birth weight.

Skeletal structure based on measured body dimensions including height, lower leg length and demi-arm span was studied to investigate the influences from age and gender, and as marker for adaptation to the effects of early growth development, to relate to coronary heart disease and predisposing risk factors. Analysis of variance with adjustments for age, social class and smoking showed that in men, short height, lower leg length or demi-arm span was associated with hypercholesterolaemia, and long lower leg length was associated with diabetes mellitus. In women, short height or lower leg length was associated with coronary heart disease. High ratio of lower leg length:height or lower leg length:demi-arm span was associated with diabetes mellitus in men. In women, high ratio of demi-arm span:height or low ratio of lower leg length:demi-arm span was associated with coronary heart disease.

A specially made tape measure, the 'Waist Watcher', was developed based on Action Level cut-offs to provide guidelines for target waist circumference. As part of a health promotion directed at general public, a prospective study was designed to assess the usefulness of the Waist Watcher for weight management in 600 men and women. Baseline data were available for analysis of the accuracy of self-reported body weight, height, and waist circumference in 101 men and 62 women. Classifications using waist Action Level 1 or Action Level 2 by the investigator were used as the reference method. Using the 'Waist Watcher' with different colour bands based on the Action Level, and photographic instructions to assess waist size, subjects classified themselves into correct categories according to Action Level 1 with sensitivities of 100% and 94.3%, and specificities of 95.0% and 96.3%, and according to Action Level 2 with sensitivities of 97.1% and 100%, and specificities of 100% for both sexes. Only 2% of the sample misclassified themselves into the wrong categories of waist circumference Action

Levels. The findings suggest that the Waist Watcher tape measure and photographic instructions can be used by the general public to assess their own waist circumference, alerting those who need weight management and screening for cardiovascular risk factors, and providing a target of desirable range of waist circumference.

Conclusions

1. New equations for men and women using simple anthropometric variables including a single measurement of waist circumference have been developed and cross-validated. These equations are robust in predicting body fatness with little error or bias from extremes of fat distribution and age. A single measurement of waist circumference provides a convenient way to assess body fatness in epidemiology and clinical situation.

2. Cut-offs of waist circumference at Action Level 1 (94 cm in men and 80 cm in women) and Action Level 2 (102 cm in men and 88 cm in women) have been derived to identify men and women at risk of overweight or central fat distribution. These Action Levels are useful in alerting public awareness of health risks associated with overweight and intra-abdominal fat accumulation.

3. Waist circumference Action Level 1 in men and in women is close to the optimal cut-offs from ROC analysis for identifying hypertension, hypercholesterolaemia or low HDL cholesterol.

4. Height has very limited influence on waist circumference as an index of adiposity, and can be neglected for practical applications.

5. Larger waist circumference associates with increased risks of chronic diseases and symptoms, cardiovascular risk factors and poor quality of life. Those with large waist circumference should take action in lifestyle modification and weight management to prevent further weight gain, and should be urged to lose weight.

6. Reduced hip circumference (i.e. reduced postural, mainly type 1 muscle fibres) was related to NIDDM independently of waist circumference (abdominal fat).

7. A moderate reduction of waist of 5-10 cm may be a useful guideline for achieving realistic targets in weight management and improving cardiovascular risks.

8. Short stature and limb lengths, and also altered skeletal proportions, which may reflect interrupted growth, are associated with several metabolic disorders. Skeletal disproportion associates with diabetes mellitus in men and CHD in women.

9. Men with natural ability in power sports are more likely in later life to develop CHD and/or predisposing risk factors than those with a natural ability in endurance sports, suggesting that muscle fibre composition may play important roles in cardiovascular disorders. Low birth weight has an independent additive effect on these disorders.

10. Waist circumference measured using the 'Waist Watcher' tape measure by subjects agrees to within (95% confidence interval limits of agreement) 6.5 cm in men and 5.3 cm in women. Using the 'Waist Watcher' tape measure, subjects self-classify their waist circumference according to Action Level 1 (<94 cm in men, <80 cm in women) or Action Level 2 (≥ 102 cm in men, ≥ 88 cm in women) with sensitivities and specificities above 94%. 'Waist Watcher' tape measure provides a valuable tool for screening health risks associated with intra-abdominal fat accumulation, in health promotion directed at the general public.

11. The findings of the present thesis contribute new knowledge in the aetiology of diseases, and also they provide an opportunity to use morphological markers of musculoskeletal development and body composition so that those who are at risk could be targeted better by health promotion directed at the general public.

ACKNOWLEDGEMENTS

Research studies in the present thesis were guided by **Professor Michael EJ Lean** (Department of Human Nutrition, Glasgow Royal Infirmary, University of Glasgow) and **Professor Jacob C Seidell** (Department of Chronic Diseases and Environmental Epidemiology, National Institute of Public Health and the Environment, Bilthoven, The Netherlands). Your teachings have provided solid foundation in my thinking and understanding of scientific research, and paved the way for my career in Medicine. I am forever in your debts.

I appreciate the continuing interest and support of my career progress from **Professor WPT James** (Rowett Research Institute, Aberdeen), **Dr Geraldine McNeill** (Department of Medicine and Therapeutics, University of Aberdeen), and **Professor Lawrence T Weaver** (Department of Child Health, Yorkhill Hospital for Sick Children, University of Glasgow).

Thanks are due to all colleagues at the University of Glasgow and the Department of Chronic Diseases and Environmental Epidemiology, National Institute of Public Health and the Environment, Bilthoven, The Netherlands, and staff from the Army School of Physical Training, Aldershot.

I cannot thank all colleagues individually who are listed in the list publications, but special thanks to **Irene Kelly**, **Aarti Soni**, **Caroline Morrison**, **Anneke Blockstra, Ruth Wouters**, and **Annie Anderson**.

I cannot apologise enough to my family (**The Han Clan**) for being away so long, but I have nearly finished studying - just another five and a quarter years, perhaps.

DECLARATION OF PERSONAL INVOLVEMENT AND EXTENT OF COLLABORATIONS IN THE PRESENT THESIS

The present thesis has used a variety of study designs, requiring large amounts of human data collection through questionnaires and measurements. I have personally designed and conducted all the analyses, personally made all the measurements and collected all the data for chapter 3, chapter 4 chapter 8, chapter 9 and chapter 10 (a total of 852 subjects) . Data from cross-sectional studies were made available through collaborations with the Dutch MORGEN Project, and WHO Glasgow MONICA Project on epidemiology for chapters 4-6. Primary data for the validation study in chapter 3.1 were provided by Dr P Deurenberg (University of Wageningen). The study of the influence of height on waist circumference as an index of adiposity re-examined data collected by myself during my MSc Magnetic Resonance Imaging Study (originally supervised by Dr G McNeill, University of Aberdeen) and also analysed data from Professor JC Seidell's Computerised Tomography Study, conducted in Wageningen. A study of the benefits from waist reduction used data from Professor MEJ Lean's follow up study of weight loss in Aberdeen.

The extent of collaborations and my personal input to the research are indicated in each chapter.

THANG SIEU HAN

Dr J Womersley
Internal examiner
University of Glasgow

Dr A Prentice
External examiner
University of Cambridge

Professor J McKillop
Convenor
University of Glasgow

ABBREVIATIONS USED IN THE PRESENT THESIS

AT	adipose tissue
BF	body fat
BIA	bioelectrical impedance analysis
BMI	body mass index
BMR	basal metabolic rate
CT	computerised tomography
CI	confidence interval
Demi-AS	demi-arm span
FFA	free fatty acids
FFM	fat free mass
HDL	high density lipoprotein
IDDM	insulin-dependent (type 1) diabetes mellitus
LLL	lower leg length
MONICA	Monitoring Cardiovascular disease (WHO study)
MORGEN	Monitoring van Risicofactoren en Gezondheid in Nederland (Monitoring Risk Factors and Disease in The Netherlands)
MRI	magnetic resonance imaging
NIDDM	non-insulin-dependent (type 2) diabetes mellitus
OIP	optimal index power

OR	odds ratio
PAR	population attributable risk
r	correlation coefficient
r^2	explained variance
ROC	receiver operating characteristics
SD	standard deviation
SEE	standard error of the estimate
SF	skinfold
UWW	underwater weighing
WHO	World Health Organisation

|| CHAPTER ONE

LITERATURE REVIEW

|| CONTENTS OF CHAPTER ONE — PAGES

1.1 Introduction

The associations of overweight and fat distribution with metabolic complications are well established (Björntorp, 1992), but the causal links remain unclear. Genetic and environmental factors and their interactions have long been considered as the main determinants of body fatness and fat distribution (Bouchard, 1990). Recent evidence emerged from studies of Barker and colleagues (1992) suggests that early malnutrition could result in irreversible damage to vital organs in order to sustain the development of the nervous system, 'programming' such subjects to greater susceptibility to metabolic disorders in certain environment, which could persist through to adult life. Early nutrition could thus be important in the development of body morphology and health, acting with genetic and environmental factors.

Studies of muscle composition have shown type 2b muscle fibres were associated with features of metabolic syndrome, including non-insulin-dependent diabetes mellitus (NIDDM) (Mårin *et al*, 1994), decreased insulin sensitivity (Lillioja *et al*, 1987), Cushing's syndrome (Rebuffé-Scrive *et al*, 1988), raised insulin and glucose concentrations (Krotkiewski *et al*, 1990), and increased intra-abdominal fat accumulation (Seidell *et al*, 1989a). All these studies found increased type 2b muscle fibres were associated with central fat distribution.

This chapter is a literature review which aims *firstly* to review existing studies on the development of overweight and fat distribution, skeletal structure, and muscle morphology, *secondly* to review the relationships between early nutrition and health in later life, and *thirdly* to seek evidence of early growth in relation to body morphology, including weight, skeletal structure (height and limb lengths), and muscle composition.

1.2 Body fat, overweight and fat distribution: an overview

1.2.1 What is overweight?

Overweight implies an excessive fat storage in an expanded adipose tissue mass. There are many methods of measuring body fat, ranging from simple anthropometric to complex computerised scanning techniques. This issue will be considered in **Chapter 3**. Because of the ease of the measurements, body mass over the of height square (kg/m^2), known as the Quetelet index (Quetelet, 1869) or body mass index (BMI), is a useful method for assessing the degree of overweight in epidemiological studies. BMI is now almost universally accepted as the measure of body fatness, the range 20-25 is considered as desirable. These figures were derived from the relationships between BMI and mortality rates (Royal College of Physicians, 1991). Garrow (1981) further defined the ranges between 25-30 and 30-40 to indicate different grades of overweight.

In Western societies, the rising prevalence of overweight adults, whose BMI exceeds 30 kg/m^2, has now reached 15-20% (Gregory *et al*, 1990; Kuczmarski *et al*, 1994; Bennett *et al*, 1995; Seidell, 1995a). Overweight clearly relates to premature death (Lew and Garfinkle, 1989) and a cluster of morbidity such as NIDDM, cardiovascular disease (CVD), and certain cancers. Quality of life in such persons is surprisingly less established, in view of their increased risk of disability (Stewart *et al*, 1983; Launer *et al*, 1994). Overweight is now increasingly accepted as a disease *per se*, imposing enormous burdens on health care resources (Colditz, 1992; Office of Health Economics, 1994; German Society for Obesity Research, 1995; Institute of Medicine, 1995; Levy *et al*, 1996; Seidell, 1995b; Sjöström *et al*, 1995; Wolf and Colditz, 1996).

1.2.2 What causes overweight?

Weight gain (i.e. fat gain) occurs when energy intake exceeds energy expenditure. The energy balance cycle (**Figure 1.2.1**) consists of many variable components. Energy intake normally in the form of ingested foods, is influenced by appetite, i.e. palatability of the food, sight and smell, which are controlled by the satiety/hunger centre located in the hypothalamus. In Western societies, food supply is not a limiting factor, but some 40% of all people consciously limit their food intake to control weight. Basal metabolic rate is the largest component of energy expenditure (~75%), influenced mainly by the proportion of lean body mass. Physical activity occupies on average about 15%, and thermogenesis about 10% of energy expenditure, foods, especially carbohydrate increase thermogenesis through dietary induced thermogenesis. Weight change results from changes in one or a combination of these components, which involves many factors in humans, making the task of identifying the aetiology of overweight extremely difficult. Genetics, environment, behaviour and medical conditions are some of major influencing factors. Although the presence of unlimited food, without the need for physical exertion to obtain it, promotes obesity, not everyone becomes overweight under those conditions. Differences between individuals in their tendency to weight gain are ultimately genetic, and genetic mechanisms may in principle operate through appetite, through power of restraint, or through metabolic mechanisms. The genetic basis of most obesity in humans is polygenic, but some potential major genetic factors are the subject of current research elsewhere. Recent epidemiological evidence suggests that early nutrition may play an important role in the development of overweight (Barker, 1992). This issue will be addressed in later sections of this chapter.

Obesity appears to run in families, though whether this reflects a genetic effect or is the consequence of a common family environment is unclear. Garn and Clark (1976) showed that the likelihood that a child will be obese is 40-50% if one parent is obese and 70-80% if both are obese. Stunkard *et al* (1986) compared the similarities between related individuals who were exposed to different environment and non-related individuals living together. They studied 540 Danish adult adoptees and both their biological and adopted parents. BMI of adopted children was observed to continue to resemble their biological parents, particularly for mothers and daughters, but there was no significant relationship with the adoptive parents.

Bouchard *et al* (1985) studied 917 subjects aged 8-26 years from more than 400 families to examine the roles of genetic and environmental influences on obesity and fat distribution. The sample included 80 pairs of adopted siblings, 95 pairs of cousins, 370 pairs of biological siblings, 69 pairs of dizygotic twins and 87 pairs of monozygotic twins. Increasing similarity in fatness and fat distribution was observed between siblings, dizygotic and monozygotic twins, but none was detected between adopted siblings. The greater heritability between dizygotic twins than between siblings must be reflecting environmental factors, since their gene similarity (50%) is the same as in siblings, on the other hand, differences in intra-uterine growth of twins - even monozygotic twins, are well described, and this could affect later growth. Significant genetic effects were found for BMI, subcutaneous fat, fat distribution, body density and fat free mass. Similarities found between children and parents and between adoptive children and foster parents indicate an influence of environmental factors. Intraclass correlations for BMI and skinfold thicknesses were almost identical in the biological and adoptive families, but extremity/trunk ratio and the proportion of total fat mass in subcutaneous sites were more closely correlated in natural than adoptive relations.

Further studies by Bouchard's group (1988) used a path analysis technique in 1698 French Canadians, including adoptive, biological, and twin relations to determine genetic and non-genetic familial influences. They found genetic transmission explained 5-30% of total variance for total body fat and fat distribution, and familial environment explained transmission of 10-30%. The ratio of subcutaneous fat from six skinfold thicknesses to fat mass from underwater weighing explained 40% of total variance transmissible between generations, from which 25% was accounted for by genetic and 15% by environmental factors, indicating fat distribution is accounted for by a large genetic component. Studies of overfeeding in twins by Poehlman *et al* (1986) and Bouchard *et al* (1990) suggest interactions between genetic and environmental factors in developing overweight.

1.2.3 Body fat distribution

Over the last ten years, fat patterning research in relation to health has re-emerged forty years since it was first suggested by Jean Vague (1947 & 1949). People with central fat distribution tend to have large proportion of body fat situated at the abdominal regions, accompanied by a relative increase in fat mass deposited within the abdomen (Ashwell *et al*, 1985; Seidell *et al*, 1988). Increased abdominal fat has been observed to relate to high risk of developing ill health, acting independently from obesity.

People with central fat distribution in both sexes tend to have a distinct body shape, said to resemble that of an apple (**Figure 1.2.2**), a physical characteristic of men, so termed 'android' by Vague, and tend to associate with metabolic abnormalities and chronic diseases (Vague, 1956; Kissebah *et al*, 1982; Lapidus *et al*, 1984; Larsson *et al*, 1984; Ohlson *et al*, 1985). There is also evidence suggesting central fat distribution is related to increased proportion of fast glycolytic muscle fibres (Krotkiewski *et al*, 1990), another masculine characteristic (Simoneau and Bouchard, 1989), and these people have been observed to have poor endurance but not poor strength in physical performance (Seidell *et al*, 1989a).

1.2.4 Regional fat cell metabolism

Studies of abdominal subcutaneous fat cells in subjects with central fat distribution showed a change in morphology with significant increase in cell volume, accompanied by an increase in androgenic/oestrogenic activity (Rebuffé-Scrive and Björntorp, 1985). Higher rate of basal and adrenaline-stimulated lipolysis was observed and these cells showed diminished sensitivity to antilipolytic action of insulin (Kissebah *et al*, 1986) and more responsive to lipolytic effect of catecholamines (Lafontan *et al*, 1985).

Increased central fat deposition relates specifically to an increase in intra-abdominal fat area on single computerised tomography (CT) scans (Ashwell *et al*, 1985; Seidell *et al*, 1988). This intra-abdominal (visceral) adipose tissue which includes the omental fat mass, has been observed to have much greater lipolytic capacity than subcutaneous fat, and contains a similar concentration of the inner mitochondrial membrane uncoupling protein (32 Kd) to that in perirenal and periadrenal fat masses (Lean and Trayhurn, 1987). This protein has been considered unique to the functionally distinct brown adipose tissue found in internal fat masses in humans, and its mRNA is detectable in insignificant amounts in subcutaneous fat (Riquier *et al*, 1984). More recently a variant uncoupling protein-2 has been identified in white adipose tissue.

Regulation of lipolysis probably depends on both insulin and catecholamines. Omental fat cells have been shown to be even less sensitive than abdominal subcutaneous fat cells to the antilipolytic effect of insulin (Bolinder *et al*, 1983). An increased lipolytic responsiveness to catecholamines was also observed in these cells. This may be related to a less pronounced adrenergic receptor response and a decrease in the ratio of α_2/β_1 receptor sites on these cell membrane (Lafontan *et al*, 1985). Changes in response to insulin and catecholamines may have effects on the increased mobilisation of free fatty acids (FFA) that drain at high levels directly into the portal vein (Rebuffé-Scrive and Björntorp, 1985), this may influence the insulin clearance by the liver (Smith, 1985). Diminished extraction and removal of insulin could be the result of direct influence by androgens (Kissebah *et al*, 1982). Increased hepatic exposure to FFA reduces hepatic clearance of insulin that may lead to increased posthepatic insulin delivery and hyperinsulinaemia (Björntorp, 1991).

The associations between increased intra-abdominal fat mass and metabolic disorders, NIDDM and CVD may be explained if an increase in plasma FFA flux is indeed a feature of central fat deposition, which may evoke and/or exacerbate the metabolic disorders. FFA may inhibit peripheral glucose metabolism and reduce insulin sensitivity. This reduction correlated inversely with the amount of glucose metabolised by peripheral tissues. (Randle *et al*, 1963; Randle *et al*, 1964). Increased FFA probably contributes to insulin resistance more than to hyperinsulinaemia, and to eventual exhaustion of β-cells of the pancreas (DeFronzo, 1988). Increased hepatic availability of FFA could stimulate hepatic FFA esterification and increase synthesis of very low density lipoprotein, thus increasing plasma triglyceride concentration, leading to raised small dense LDL, which is highly atherogenic (Austin *et al*, 1990; Griffin *et al*, 1994). FFA may inhibit cholesterol esterifying capacity and thus decrease the acquisition of cholesterol by high density lipoprotein particle.

1.2.5 Methods of measuring body fat

Underwater weighing is the conventional 'reference standard' (**Figure 1.2.3**) for a two-compartment model, which measures body density from which fat and lean mass content are estimated assuming standard figures for density of these components (Siri, 1961). Other robust methods include the total body potassium method measuring intracellular fluid by detecting the natural radioactive ^{40}K isotope (Boddy *et al*, 1972), and measurement of the total body water by dilution of a deuterium labelled water dose (Schoeller *et al*, 1980). The principles for these techniques are described in detail elsewhere (Brodie, 1980; Garrow, 1983; Shephard, 1991). More complicated multi-compartment models of body composition including bone mass are under development.

For routine clinical and epidemiological use, simpler and cheaper anthropometric measurements have been used to predict body composition in relation to body density by underwater weighing. Various combinations of anthropometric measurements have been used as independent variables. Shephard (1991) reviewed the extensive literature and found few truly practical anthropometric approaches to predict body density or fat content. The most widely used method, that of Durnin and Womersley (1974) used the $\log_{10}$ sum of four skinfolds measured at biceps, triceps, subscapular and suprailiac sites (**Figure 1.2.4**). Jackson and his colleagues (Jackson and Pollock, 1978; Jackson *et al*, 1980) used the sum of three or seven skinfolds in combination with waist and forearm circumferences or gluteal circumference, and age for generalised regression equations. These approaches have not been subjected to systematic validation in separate samples or populations. Recently, Deurenberg *et al* (1991) suggested that BMI with age and sex can predict body density with an accuracy similar to that of skinfold methods in a large sample of Dutch population. McNeill *et al* (1991) observed skinfold method to be as good as bioelectrical impedance, body water dilution, and better than ^{40}K counting methods relating to underwater weighing in normal weight and overweight women. Reilly *et al* (1994) found the skinfold method (Durnin and Womersley, 1974) to underestimate body fat in small sample ($n = 16$) of 70 year old women.

1.2.6 Assessment of body fat distribution

The re-emergence of fat patterning studies was further advanced by the invention of the CT scanner. This approach enables scientists to 'view directly' the fat masses distributed over different sites in the body, and relate them to metabolic variables (Seidell *et al*, 1989b). Due to a radiation exposure of 2 mSieverts/exposure (annual permitted exposure to X-rays in Britain is 5 mSieverts), X-ray CT use is limited *in vivo*. Only small numbers of volunteers have been studied by a few centres, with limited number of scans made. Abdominal (intra-abdominal and subcutaneous) fat areas calculated from CT scans were used to validate anthropometric indices of fat distribution such as ratios waist to hip (Ashwell *et al*, 1985) or waist to thigh (Seidell *et al*, 1988), and various body diameters (van der Kooy *et al*, 1993), and in a variety of clinical conditions (Lean, 1986).

Fat volumes estimated by three dimension reconstruction from adjacent scans may provide a more meaningful picture of fat distribution than cross-sectional areas. The use of magnetic resonance imaging (MRI) (**Figure 1.2.5**) is safer than CT scanning, thus more images can be made to calculate fat volumes in human subjects, and the procedure may be repeated on the same subject for observations of changes in body composition and fat distribution. McNeill *et al* (1991) showed a good agreement between total body fat calculated from the sum of fat volumes obtained by MRI and the established underwater weighing method in women. Sohlström *et al* (1993) used an MRI machine with low magnetic field strength (0.02 Tesla), and observed similarly good agreement with underwater weighing technique for estimating total body fat in Swedish women. Abate *et al* (1994) compared subcutaneous and intra-abdominal fat volumes estimated by MRI (0.35 Tesla), and the actual fat volumes dissected from three human cadavers, including two males and a female showed the two methods only differed slightly (mean difference = 0.08 kg; 95% confidence interval = 0.01 to 0.15 kg). Potentially, MRI could be used as the 'reference method' for measuring body fat distribution and for validating anthropometric measures including waist and hip circumferences (**Figure 1.2.6**).

1.2.7 *Legends of figures in chapter 1.2*

Figure 1.2.1. The energy balance cycle (page 11).

Figure 1.2.2. Silhouette photographs showing variation in body fat distribution in men (a & b) and in women (c & d). Subjects have similar body mass index, but the male (b) and female (d) patients with non-insulin dependent diabetes mellitus have higher waist to hip ratio, indicating a more centralised fat distribution (page 12).

Figure 1.2.3. Measuring total body density by underwater weighing to estimate body composition (page 13).

Figure 1.2.4. Common sites for measuring subcutaneous skinfold thicknesses to predict total body fat by underwater weighing (page 14).

Figure 1.2.5. Magnetic resonance imaging (MRI) machine for scanning body tissues (page 15).

Figure 1.2.6. Measuring body fat distribution using anthropometry according to the World Health Organisation (1995) standard recommendation. Waist circumference between the lowest rib margin and top of the lateral iliac crest (a), and maximum hip circumference at the greater trochanters (b) (page 16).

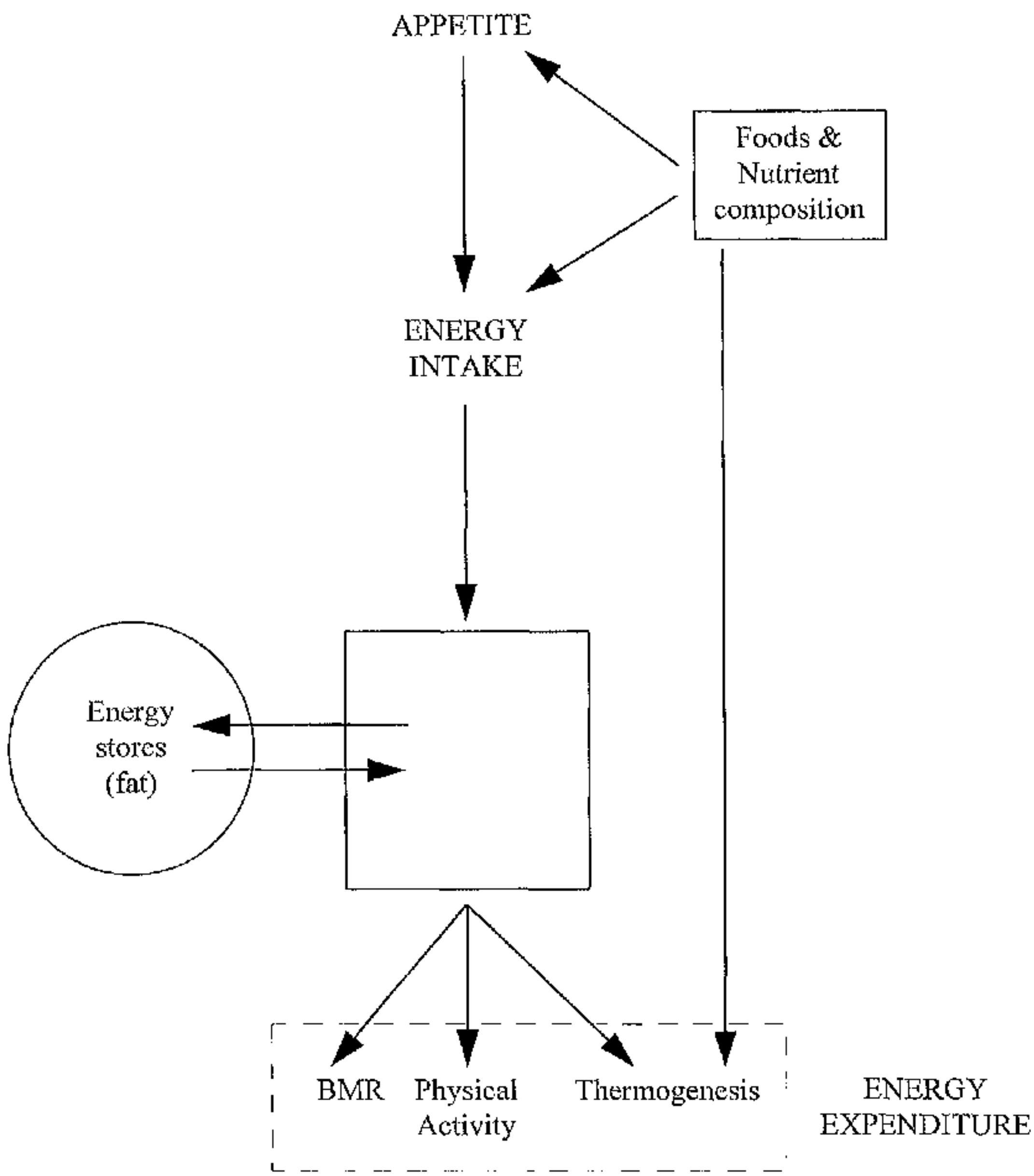


Figure 1.2.1. The energy balance cycle.

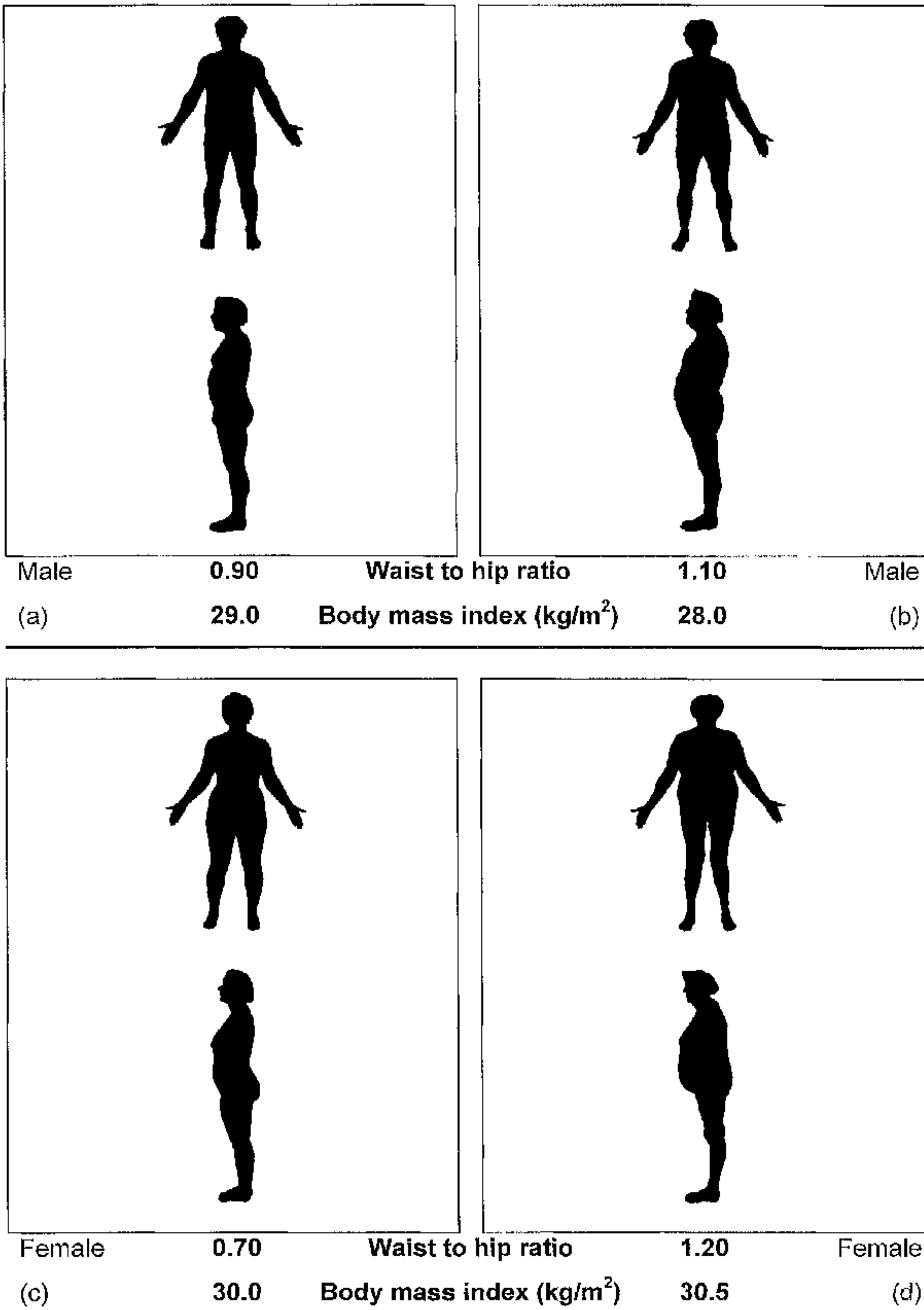


Figure 1.2.2. Silhouette photographs showing variation in human body fat distribution.

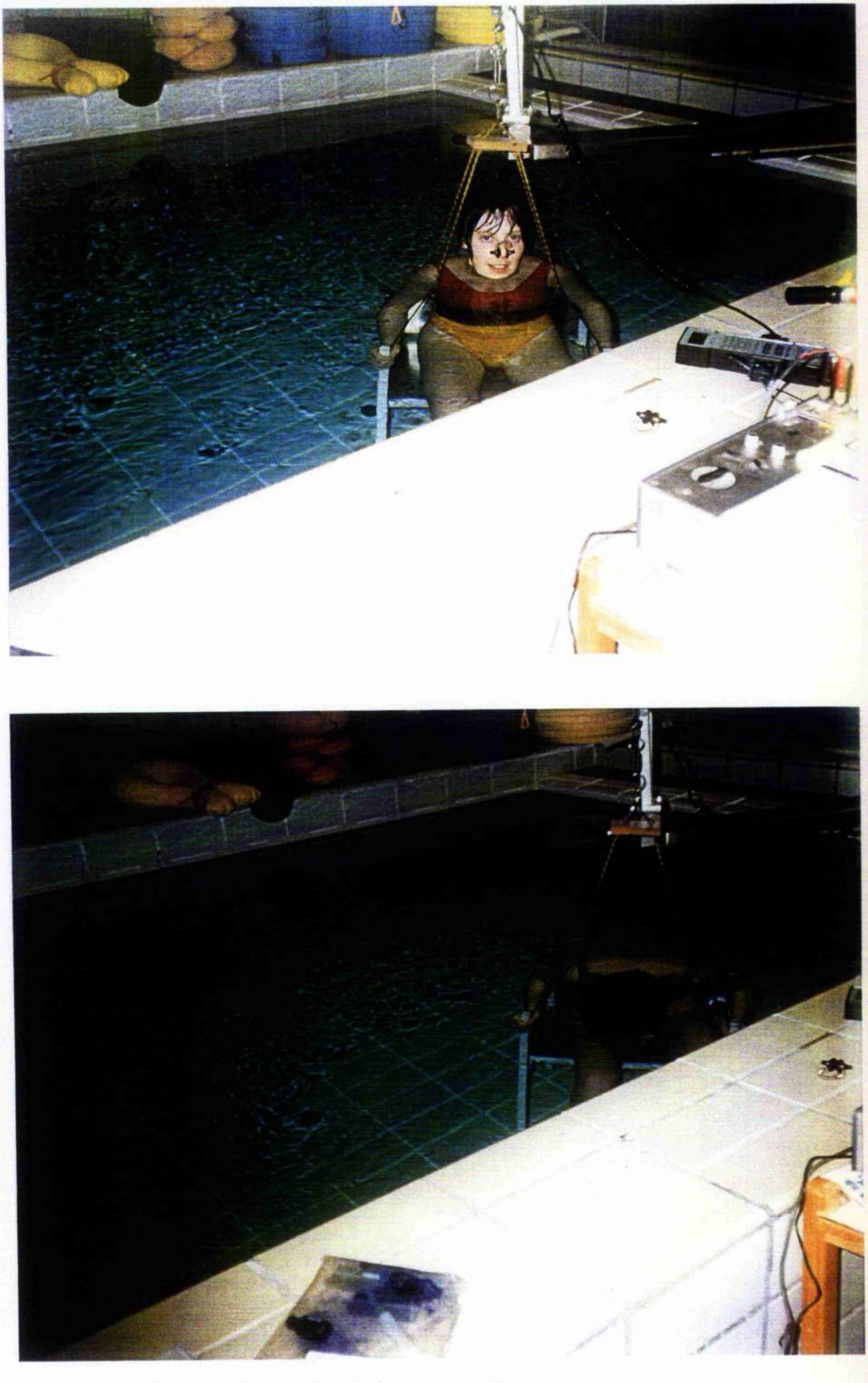


Figure 1.2.3. Measuring total body density by underwater weighing.

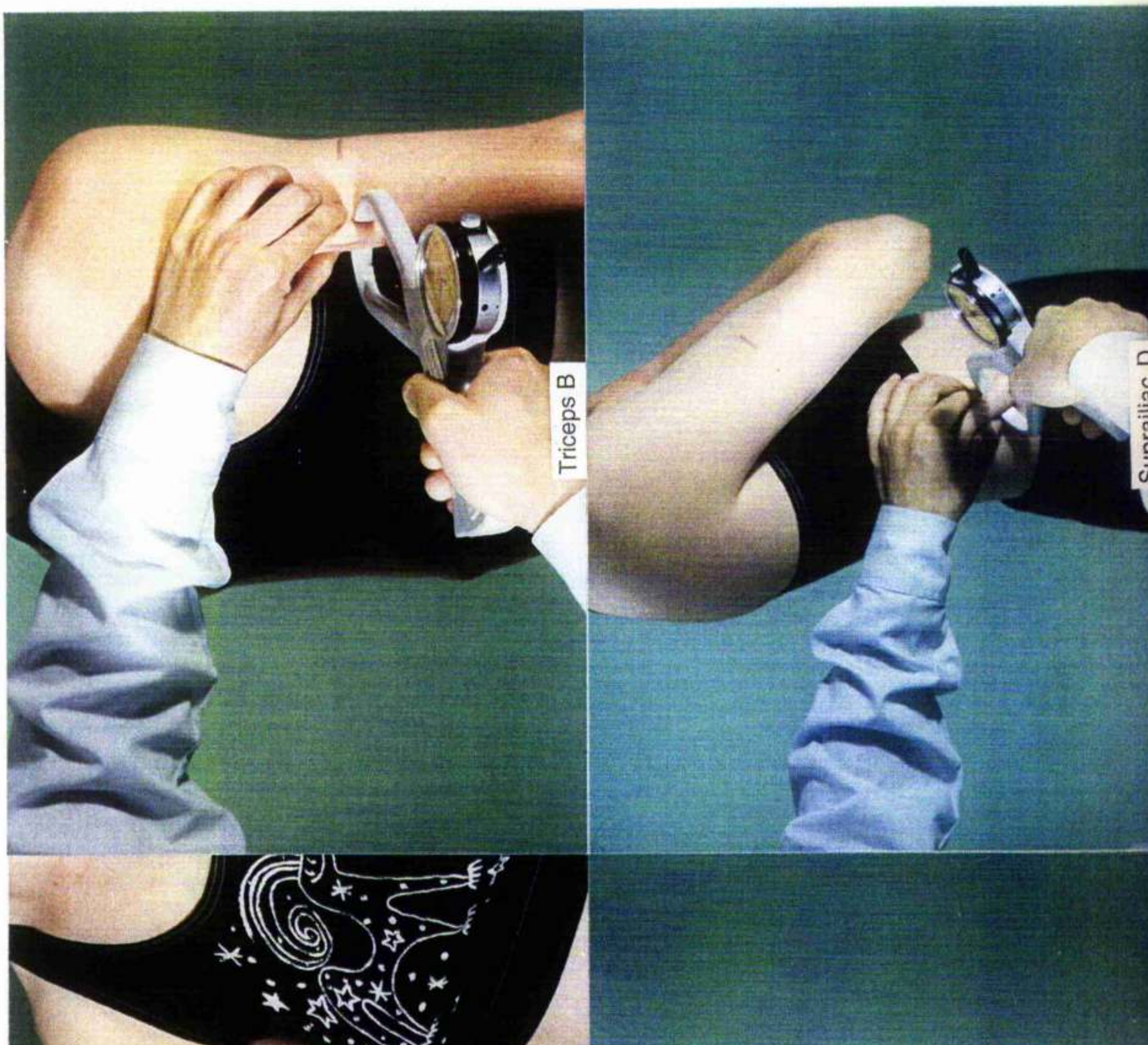
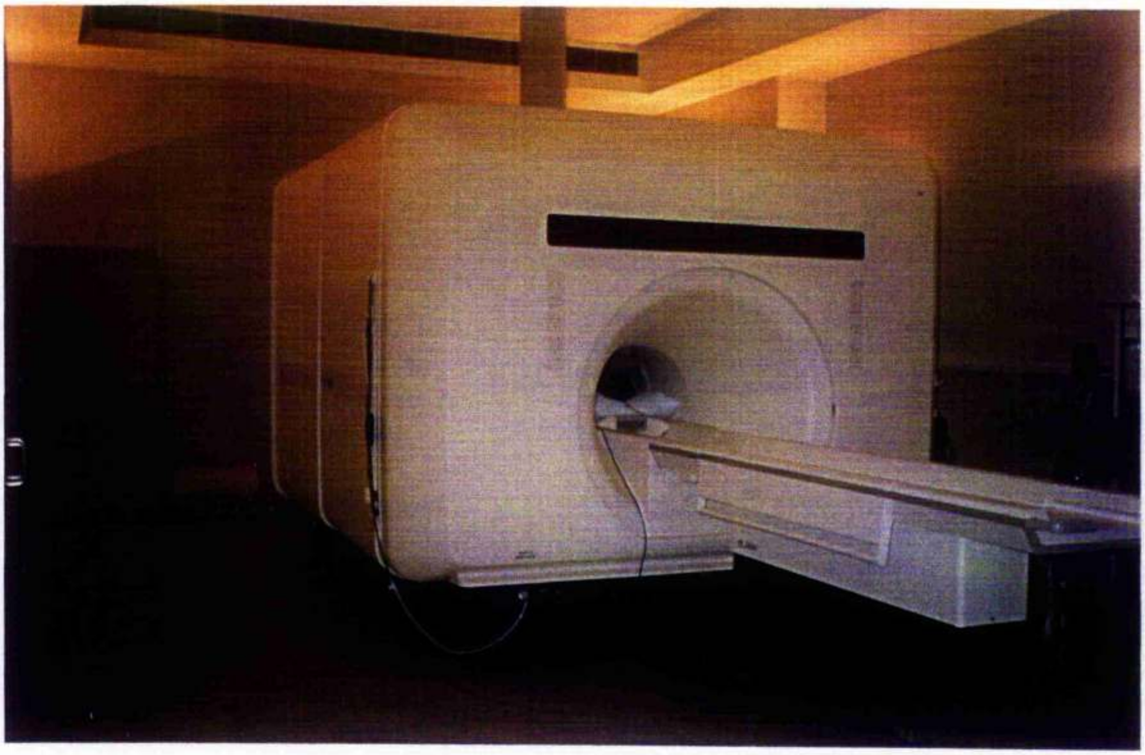


Figure 1.2.4. Measuring skinfold thicknesses using skinfold calipers.



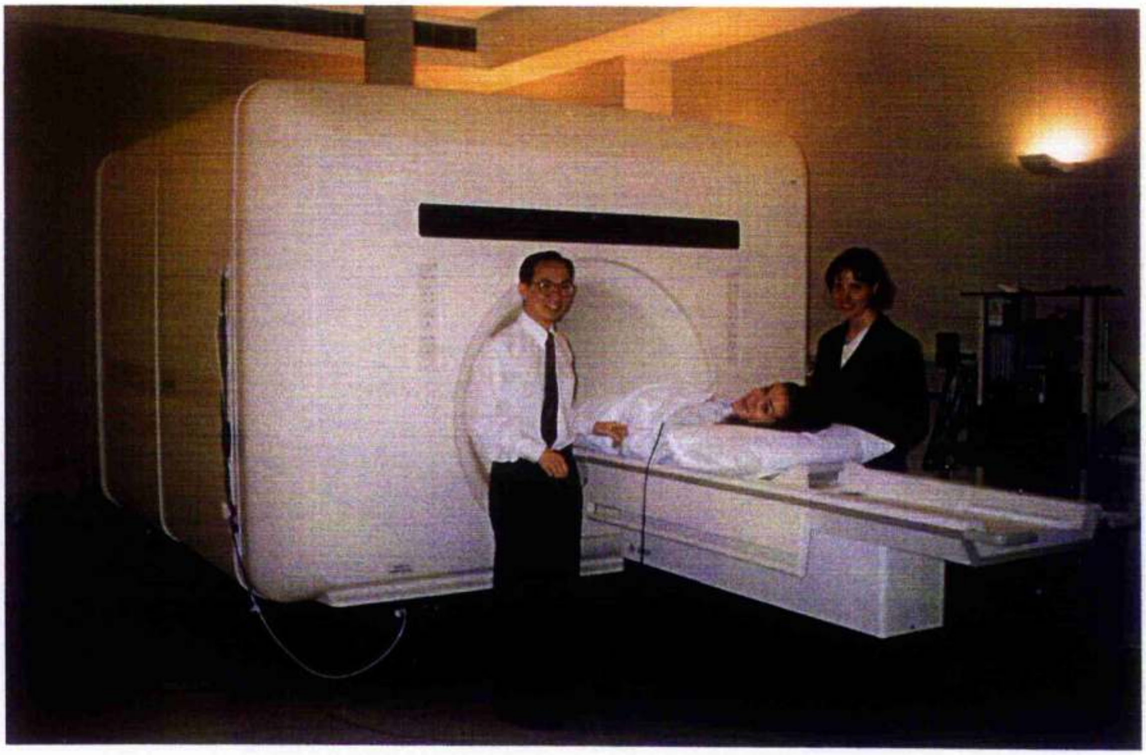
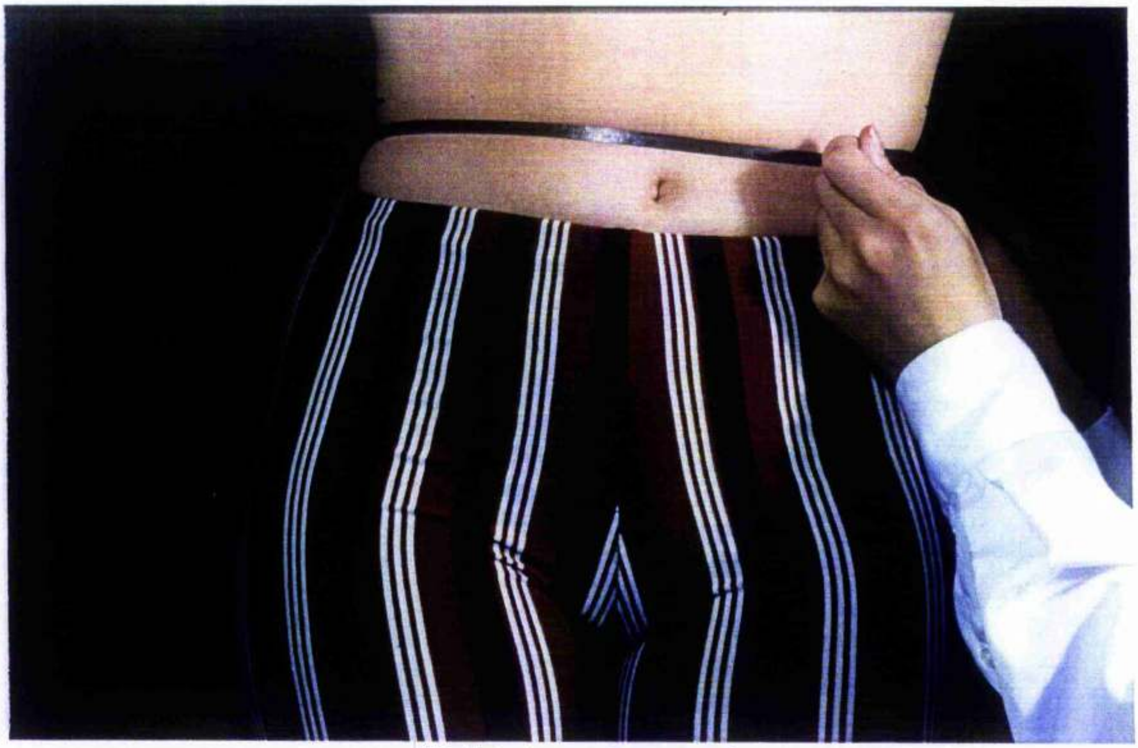


Figure 1.2.5. Magnetic resonance imaging (MRI) machine for scanning body tissues.



Waist circumference A

Hip circumference B

Figure 1.2.6. Assessing body fat distribution from body circumferences.

1.3 Skeletal structure

1.3.1 A global view of the trends in height changes over time

Average height varies between countries, races, areas, and social classes *etc.* Like body weight or body fatness, genetic and environmental factors are thought to be the main determinants, but their relative contributions are not apparent. There exists a wide range of adult heights in various parts of Africa. Just 200 years ago, Norwegian men who are now amongst the tallest in the world were only as tall as the Bushmen's present height (Eveleth and Tanner, 1976). Martorell and Habicht (1986) found that although there were height differences amongst the tallest boys in high social class from different countries, height differences between social classes within a country were much wider, particularly in countries where there is a huge gap between the rich and the poor. In India, the height gap between classes in the nineteen-eighties was similar to that existed in Britain over 150 years ago (Floud *et al,* 1990), reflected in the military recruits at Sandhurst (high social class) and Marine Society (low social class from the London Slums). Height differences between social classes have been narrowing steadily in Britain, but the gap is wider than that of many European countries. In general, there has been steady trends towards height increase over the past 100 years in developed countries (Floud, 1990).

1.3.2 Nutritional status and height

Malnutrition or nutrition depletion through infection affects height growth during early development. Martorell and Habicht (1986) have shown that the length of children up to 2 months old from developing countries is near the 50th percentile of the growth chart, but begins to fall after that. Explanations for this trend may be that at the early stage, the child receives enough energy and anti-infective property from breast milk, but growth begins to fail if it continues to breast feed since energy from breast milk cannot adequately provide the growing child, or if the child begins to wean, there is a higher chance of contact with infected substances. Nutrition and health care clearly help infants grow better in developing countries.

There is no direct evidence for height as a marker of nutritional status, but historical evidence has provided remarkable parallel trends in changes in height with various factors that can influence nutritional status. For example, the rapid gain in height of English working-class children coincides with the steep rises in life expectancy in England, wages, and consumers' expenditure, all occurred around the same time at about 1820-1850 (Floud *et al*, 1990).

1.3.3 Height and health

Height has long been used as an indicator of health. Army and police recruits must achieve a certain height for selection. Taller slaves were bought at a higher price as they were thought be stronger, thus more productive (Fogel, 1986). Subjects of short stature have been shown to have increased risk of premature death (Waaler, 1984), particularly in younger age groups, indicated by steeper gradients. Similar to body mass index (Andrés *et al*, 1985), the differences in mortality rates become less marked between groups in the elderly. A study of Fogel *et al* (1986) has shown that Union Army (United States) rejection rates due to poor health were higher in shorter subjects.

1.3.4 Limb lengths in relation to height

Whilst different body proportions exist between adults of different races (Reeves *et al*, 1996), and that it has been suggested that growth failure *in utero* at different periods of pregnancy may result in altered body morphology (Barker, 1994), evidence has indicated that improved standards of living with adequate nutrition has brought the body proportions of Japanese children nearer to the reference standards of the British (Tanner *et al*, 1982). Increase in height, or specifically leg length reflects improvement in health and growth (Tanner *et al*, 1982).

Early growth is clearly affected by under feeding in experimental animals (McCance, 1968). Disproportionate growth, e.g. longer or shorter legs than expected for height occurs with delayed puberty (Tanner, 1971), but associations with metabolic disorders are not described.

1.4 Muscle morphology and function

1.4.1 Characteristics of muscle fibres

The primary function of the skeletal muscles is performing contractions. The muscle is not homogeneous. All human skeletal muscles have a mixture of muscle fibres. Different muscles contain different types of fibres in varying proportions, serving a wide range of demands. The content of different fibre types associates closely with the speed, intensity, duration and types of contractions.

In terms of the speed of contractions, human muscle fibres are classified as type 1 (slow twitch), and type 2 (fast twitch). Based on histologic profile, type 2 (fast twitch) fibres are further subdivided into at least 2 different types, 2a and 2b (Brooke and Kaiser, 1970). Based on their dynamic and metabolic behaviour, type 1 muscle fibres are known as slow oxidative, type 2a as fast oxidative-glycolytic and type 2b as fast glycolytic. Other muscle fibres have also been identified. Type 2c are thought to be transitional fibres between type 1 and 2. There may be 'dormant' stem cells which may function as replacement for damaged fibres (Jones and Round, 1990).

Type 1 muscle fibres have high oxidative capacity, with high mitochondrial and capillary densities and are red in appearance. Their major substrates are circulating FFA and intra-muscular glycogen, being utilised by the oxidative phosphorylation pathway. Type I muscle fibres are highly fatigue resistant at slow speed of contraction, such as postural maintenance during habitual activity.

In contrast to type 1, type 2b muscle fibres have low respiratory capacity and high glycolytic enzyme activity. They have low mitochondrial and capillary densities and appear white. The main substrate is muscle glycogen, used anaerobically (not dependent on oxygen) by the glycolytic pathway producing lactic acid. These muscle fibres can contract rapidly with very high power output for explosive activity, but they fatigue easily with an associated accumulation of lactic acid.

Type 2a fibres are intermediate between type 1 and type 2b muscle fibres. They are high in both glycolytic and oxidative enzyme activities. These muscle fibres can perform fast contractions and relatively fatigue resistant, using glycogen as their main substrate with moderate amount of FFA.

There is a hierarchical recruitment of muscle fibres according to functional demands (Henneman, 1965). Type 1 muscle fibres are recruited at both low and high speed of contraction, whereas type 2 muscle fibres are relatively inactive at low speed and recruited when type 1 muscle fibres are fatigued or at high speed of contraction, such as in sudden bursts of action, and high workload.

The choice for fuel utilisation mainly depends on energy demands. More glycogen is used with increasing rate and intensity of workload, as energy is converted much faster from glycogen than FFA. Endurance training can have a glycogen sparing effect by increasing the capacity for FFA oxidation for a given workload. Other factors could also affect substrate preference include diet composition, substrate availability, and hormonal and enzymatic activities (Åstrand and Rodahl, 1986).

1.4.2 Muscle morphology: nature or nurture?

On average, healthy subjects have about half and half of slow and fast twitch fibres in the commonly biopsied vastus lateralis, deltoid and gastronemius muscles, but the range of type 1 muscle fibres varies from 10% to 90% between individuals (Saltin and Gollnick, 1983). Athletes who specialise in 'aerobic' sports, such as marathon runners, tend to have high proportion of slow twitch (type 1) muscle fibres, while those who specialise in anaerobic sports, such as 100 m sprinters or weight lifters, tend to have high proportion of fast twitch (type 2a and 2b) muscle fibres (Åstrand and Rodahl, 1986; Fox *et al*, 1988).

It is unclear whether the difference of muscle composition between athletes engaging in different types of sport is primarily due to genetic or training effects. Howald (1982) suggested self selection for sports activities may exist in early life. Young people with predominant type 1 muscle fibres may be more physiologically suited, and so attracted to endurance sports, while those with higher type 2 fast twitch fibres prefer sprinting events. Komi *et al* (1977) showed monozygotic twins have more similar proportion of slow twitch type 1 muscle fibres than dizygotic twins in the vastus lateralis, with estimated heritability of 99.5% in males and 92.2% in females. Trained athletes including cyclists, canoeists, runners, weight lifters had similar proportion of muscle fibres in the vastus lateralis (leg) as the deltoid (upper body), whereas enzyme activities were higher in muscles associated with frequent use (Gollnick *et al*, 1972).

Studies of physical training have shown conflicting results as to whether training can have an effect on muscle fibres transformation (Andersen and Henriksson, 1977, Saltin *et al*, 1968). Endurance training is associated with increased aerobic capacity of the muscle, such as increased capillary (Andersen and Henriksson, 1977) and mitochondrial proliferation, accompanied by increased oxidative enzyme activities (Henriksson and Reitman, 1977). These results do suggest some capacity towards a greater functional similarity to type 1 muscle fibres.

Decreased physical demands tend to shift muscles towards type 2 muscle fibre characteristics. Animals with spinal cord section, where the muscles are inactive and relieved from all neural influence, have most of their type 1 muscle fibres transformed to type 2b (Salmons and Vrbová, 1969). Paraplegic patients have high proportion of type 2 muscle fibres (almost 100%) in their paralysed lower limbs, whereas their unaffected upper limbs have similar proportions of fibre types to healthy subjects (Grimby *et al*, 1978). Detraining in an Olympic cross country skier due to injuries decreased his type 1 muscle fibres from 81% to 57% (cited by Howald, 1982). Similarly, Howald (1982) reported a decrease in type 1 muscle fibres from 73% to 69%, and an increase in type 2 muscle fibres in a long distance runner who reduced his training intensity due to health problems for 6 months, from 100 km/week to 40 km/week. When the intensity increased to 110 km/week, type 1 muscle fibres increased to 77% with a corresponding decrease in type 2 muscle fibres. Patients who had knee surgery also reduced their type 1 muscle fibres in just 5 weeks (Häggmark *et al*, 1981).

1.4.3 Electrical stimulation and muscle morphology

Almost by chance, Buller *et al* (1960) discovered that when the nerves of fast twitch, white muscle (flexor digitorum longus) and slow twitch red muscle (soleus) of cats were crossed over, after a period of time, the speed of contraction of the fast twitch white muscle became slower and this muscle became red in appearance resembling that of the slow twitch red muscle. Similarly, the slow twitch red muscle fibres became faster and whiter. These workers ruled out the influence of neural impulse, and postulated that the transformation was induced by a chemical substance from the supplying nerve.

Severing of the tendon (tenotomy) of the slow twitch soleus muscle from the bone Vrobová (1963) or immobilising the limbs (Fischbach and Robbins, 1969) has the effect of increasing the speed of contraction of the slow twitch soleus muscle. The change to fast speed could be prevented by low frequency electrical stimulation (5 or 10 Hz), but not by higher frequencies (20 or 40 Hz) within 3 weeks (Salmons and Vrobová, 1969). Later, it was shown in rabbits that after cross innervation, the slow twitch red muscle (soleus) which was supplied by the nerve originally from the fast twitch white muscle (extensor digitorum longus) acquired the physiological and biochemical characteristics similar to the fast twitch white muscle, and this transformation could be prevented by electrical stimulation to the supplying nerve at low frequency (10 Hz) in 8 weeks (Salmons and Sréter, 1976). These observations demonstrated that muscle transformation was probably independent of any chemical substance released from the serving nerve suggested by Buller *et al* (1960), and that muscle fibre characteristics are greatly influenced by the patterns of neural impulse and duration of stimulation. The transformation is reversible, Sréter *et al* (1975) have shown the initial rabbit fast twitch white muscles became red slow twitch muscles as a result of low frequency electrical stimulation, regained their former characteristics when the stimulus was removed.

1.4.4 Ageing and muscle morphology

Histological evidence of muscle specimens from the elderly at autopsy often shows areas of fibre type grouping, *i.e.* the whole fascicle containing only type 1 muscle fibres (Jones and Round, 1990), suggesting that all adjacent fibres are re-innervated by one type of motor neuron, and the there is probably an increase in size of the motor unit (an increase in the number of fibres innervated by each nerve). As a consequence, fine motor control in the elderly is diminished, resulting in shaking of the hands and fingers *etc.*

1.4.5 Muscle morphology and metabolic disorders

Bonen *et al* (1981) have shown predominant type 1, slow twitch red muscle (soleus) of rats are more sensitive to insulin than white, fast twitch muscles (plantaris and extensor digitorum longus). Single animal type 1 muscle fibres are more sensitive to insulin than type 2 muscle fibres (Eisenburg, 1983; Hom and Goodner, 1984). In non-diabetic men, increased proportion of type 1 muscle fibres and capillary density are associated with higher insulin sensitivity (Lillioja *et al*, 1987).

Before puberty, boys and girls (6 years old) have been shown to have higher proportion of type 1 muscle fibres than adults (Bell *et al*, 1980). Men tend to have higher proportion of type 2 muscle fibres than women (Simoneau *et al*, 1989). Wade *et al* (1990) have observed that compared to leaner subjects, overweight subjects have lower proportion of type 1 muscle fibres and they oxidised less FFA during aerobic exercise. Subjects with central fat distribution and those with NIDDM have been shown to associate with increased proportion of fast twitch type 2 white fibres and decreased capillary density (Lillioja *et al*, 1987; Märin *et al*, 1994). Holmäng and co-workers have shown strong relationships between different hormones and muscle morphology and function. Excess cortisol (Holmäng *et al*, 1992a) and testosterone (Holmäng *et al*, 1992b) in female rats have been shown to shift the muscle towards type 2 muscle fibres and reduce capillary density with diminished sensitivity to insulin. Rats made hyperinsulinaemic by implantation of osmotic mini-pump increased the proportion of type 2 muscle fibres in 7 days, but in contrast to cortisol and testosterone, capillary density and insulin sensitivity were increased in all fibre types (Holmäng *et al*, 1993). These workers suggested that capillary density (blood supply) is important for determining insulin sensitivity, and that muscle composition may be a consequence rather than a cause of hyperinsulinaemia. In humans, hyperinsulinaemia have also been observed to strongly associate with increased capillary density in all muscle fibres, especially around type 2b muscle fibres (Eriksson *et al*, 1994) in prediabetic men: These subjects had impaired glucose tolerance and after 15 years, developed NIDDM. Oestrogen causes a decrease in rat muscle fibre diameter (Suzuki *et al*, 1985). Lithell *et al* (1981) have observed high correlations between serum insulin (r = 0.87, P <0.001) and blood glucose (r = 0.51, P <0.05) with muscle fibres area/capillary ratio.

Physical activity can protect against development of NIDDM (Manson *et al*, 1991), cardiovascular disease (Morris *et al*, 1953a & b; Paffenbager *et al*, 1970), and increase life expectancy of IDDM (Moy *et al*, 1993). NIDDM has an important genetic component. The muscle fibre type of children of NIDDM parents has not been examined previously. However NIDDM is associated with a relative lack of exercise, which itself may favour a shift of metabolic activity towards type 2 muscle fibres.

Cross-sectional studies have found associations between type 2b muscle fibres and features of metabolic syndrome X (Lillioja *et al*, 1987; Lillioja & Bogardus, 1988; Rebuffé-Scrive *et al*, 1988; Krotkiewski *et al*, 1990; Mårin *et al*, 1994).

1.4.8 Other effects on muscle morphology

Increased oxygen supply to muscle is probably a feature of endurance training, associated with type 1 muscle fibre predominance. It seems possible that hypoxia, e.g. smoking, vascular disease, and sleep apnea could lead to an adaptive response of the muscle towards characteristics of type 2, glycolytic muscle fibres.

1.5 Evidence linking early malnutrition and altered body morphology

Barker and colleague's studies centred on the relationships between early development and metabolic disorders in later life. Although Barker (1994) mentioned the importance of the skeletal muscle and body morphology in describing the 'thrifty phenotype' and 'programming' hypotheses, it is surprising that there has been only one published study on body fat distribution in relation to early growth in men by Barker's group (Law *et al*, 1992), we have since performed similar studies on women (Han, 1994; Han *et al*, 1995a).

We have found only one study by Barker's group on skeletal structure (height) in relation to early growth and metabolic diseases (Barker *et al*, 1990). Development of stature has previous been examined in detail by many studies, notably those of Tanner (1989). Floud *et al* (1990) have gathered a huge amount of historical evidence of the influence of nutrition on height development.

1.5.1 Birth weight and body fat distribution

In a large retrospective study of men born in Hertfordshire (n = 845) and Preston (n = 239), Law *et al* (1992) have shown the men's current waist to hip ratio significantly (P <0.05) increased with low birth weight, and low birth weight relative to placental weight, adjusted for BMI. We have performed similar analysis on 46 women and shown that low birth weight was associated with large waist circumference (Han *et al*, 1995a), indicating increased intra-abdominal fat mass deposition (Han *et al*, 1995b). In the same study of the women, low birth weight was also associated with a tendency for elevated blood pressure and heart rate, indicating poor cardiovascular function (Han *et al*, 1996a). Valdez *et al* (1991) found an inverse relationship between birth weight and the ratio of subscapular to triceps skinfold thickness rather than with waist to hips ratio.

1.5.2 Early nutrition and the development of body stature

The main factors affecting height growth have been identified as low social class, lower birth order, low mother's height, large number of siblings, low birth weight, young mother (<25 years), and heavy smoking mother during pregnancy (Floud *et al*, 1990). Amongst these factors, birth weight appears to have a big influence on height. Martorell and Habicht (1986) have emphasised the limiting factor of early growth in the development of body stature as, "After early childhood, it is rare for the rate of growth to be fast enough for children to regain the centile position in height which they had in early infancy, and this period of restricted growth therefore leaves a permanent legacy: (1) growth impairment during the first few years of life largely determines the small stature exhibited by adults from developing countries; and (2) with a malnourished population, those who exhibit a greater degree of stunting as young children are those who are the shortest as adults."

Boyd Orr (1928) was probably the first to note the importance of early nutrition on body development. Children aged between 5-14 years were given milk or biscuits of the same calories in addition to their school diet. After seven months, those who received either fresh or skimmed milk grew 20% taller than control group (without supplements), while those who had biscuits as supplements did not differ from control group. This study showed the importance of protein in body development of children, which led to subsequent guidelines for growth improvement in children (FAO/WHO/UNU, 1985).

1.6 Relationships between early nutrition and health in later life

So far in the review, only genetic and environmental factors have been considered as determinants of body morphology and diseases. The past ten years saw Barker and colleagues (1992 & 1994) produce a host of evidence showing striking relationships between poor early growth and metabolic disorders in later life. Two hypotheses, the 'thrifty phenotype' and 'programming', were used to describe these relationships to suggest that early exposure to adverse conditions, including fetal malnutrition as reflected by low birth weight, or perinatal nutrition depletion (infection), as reflected by infant weight and mortality rates at the time the subjects were born, may predispose subjects to higher susceptibility to develop chronic diseases including bronchitis, ischaemic heart disease and NIDDM.

1.6.1 The 'thrifty phenotype' hypothesis

In describing the associations between body size at birth and impaired glucose tolerance in later life, Barker has suggested that, "... poor nutrition in fetal and early life is detrimental to the development and function of the β cells of the islets of Langerhans, and changes in tissues, primarily muscle, which respond to insulin production or in the sensitivity of the tissues to it disposes to the development of NIDDM; adult influences, including obesity, ageing, and physical inactivity, determine the time of onset and severity of the disease.

According to the 'thrifty phenotype' hypothesis, NIDDM is the outcome of the undernourished fetus and infant having developing with some reduction in size and/or function of vital organs, including the endocrine pancreas. For as long as the individual remains undernourished, its limited glucose-insulin metabolism is adequate. A move to over- or good nutrition with expansion of adipose tissue mass, however, exposes the deficiencies in β cell function, and tissue sensitivity to insulin action, impaired carbohydrate tolerance and diabetes results."

1.6.2 The 'programming' hypothesis

Lucas (1991) proposed the 'programming' hypothesis to suggest that a stimulus or insult at a critical period of development has lasting or lifelong significance, has led to Barker's (1994) arguments that, "...undernutrition *in utero* and during infancy permanently changes the body's structure, physiology, and metabolism, and leads to coronary heart disease and stroke in adult life. Four underlying principles of the 'programming' were established based on animal studies. *First*, undernutrition in early life has permanent effects. *Second*, undernutrition has different effects at different times in early life. *Third*, rapidly growing fetuses and neonates are more vulnerable to undernutrition. *Fourth*, the permanent effects of undernutrition include reduced cell numbers, altered organ structure, and resetting of hormonal axes."

|| CHAPTER TWO

AIMS, HYPOTHESES, RESEARCH QUESTIONS, AND RATIONALE OF THE PRESENT THESIS

|| **CONTENTS OF CHAPTER TWO** — **PAGES**

2.1 Aims, hypotheses and selection of research questions

The present thesis aimed to achieve four major objectives in the study of components of body morphology (adiposity, skeletal structure, muscle composition) and related metabolic disorders.

1. *Firstly* to develop simple scientifically valid and practical methods for assessing specific components of body morphology.

2. *Secondly* to establish the relationships between measures of body morphology and a range of metabolic disorders and ill health.

3. *Thirdly* to study some determinants of body morphology and related metabolic disorders.

4. *Subsequently*, the findings on the implications of altered body morphology on health risks were applied towards health promotion, to devise elements for strategies directed at general public.

- The following hypotheses and research questions were postulated and tested to achieve the main objectives listed above.

2.1.1 Development of simple and practical methods for assessing body morphology

Existing evidence prior to the present thesis

The current increasing trends in prevalence of overweight and the lack progress prevention and treatment of this 'disease' are probably due both to the lack of public awareness of health risks associated with overweight, and the lack of readily available methods for health professionals to assess both body composition and adverse fat distribution, combined with unattainable and inappropriate targets for management.

Hypothesis

A novel simple anthropometric measure can be validated for identifying those with excess fat or adverse fat distribution.

Research questions

Are existing methods of measuring body morphology satisfactory in terms of accuracy and practicality?

Can a better novel method be derived to reflect central fat and total adiposity?

2.1.2 Relationships between body morphology and metabolic disorders

Existing evidence prior to the present thesis

Waist circumference is amongst a variety of different anthropometric indicators of intra-abdominal fat. Excessive intra-abdominal fat accumulation is associated with increased metabolic risks. Body composition studies using scanning technique have identified the waist circumference as its proxy.

Hypothesis

Waist circumference identifies those at increased health risk.

Research question

How well does waist circumference relate to metabolic disorders compared to the existing methods of body mass index and waist to hip ratio?

2.1.3 Some determinants of body morphology and metabolic disorders

Existing evidence prior to the present thesis

Animal studies have shown diet imbalance during early growth can affect skeletal structure.

Cross-sectional studies have found associations between type 2b muscle fibres and features of metabolic syndrome X. Athletes who are specialised in power sports tend to have type 2b muscle fibre predominance. Further, according to the 'thrifty phenotype' hypothesis used to explain the relationships between early growth and metabolic disorders, muscle morphology may also be affected by early growth. It is possible that there may be many more hierarchical steps to sustain growth of more vital organs, e.g. the nervous system, visceral organs and musculoskeletal system in that order. In the present studies, it is hypothesised that the musculoskeletal system may be one of the first body organs to be 'sacrificed'.

Hypotheses

People with limb lengths longer or shorter than expected, which may reflect interrupted early growth, are more at risk of metabolic disorders in later life.

People with a natural ability in power sports (a presumed marker of type 2 muscle fibres) more likely to develop metabolic disorders than those with a natural ability in endurance sports (a presumed marker for type 1 muscle fibres) in later life, and low birth weight influences their relationship.

Research questions

Does disproportionate stature (limb lengths relative to height) associate with health hazards?

Is the musculoskeletal system affected by low birth weight, contributing to altered body functional capacity in adult life?

Do individuals with declared natural ability in power sports suffer higher rate of coronary heart disease?

2.1.4 *Implications of altered body morphology on health risks applied towards health promotion*

Existing evidence prior to the present thesis

Failure to check increase in obesity urges the need for the use of the simple measurement of waist circumference for assessing health risk, directed at the general population.

Hypothesis

Self measurement of waist circumference is a robust guide to the need for weight management.

Research questions

Is self-reported waist circumference reliable?

Does a patent 'Waist Watcher' tape measure improve self-measurement?

2.2 Rationale for selection of study designs and methods for the present thesis

To be able to address the hypotheses satisfactorily in the present thesis, a wide range of multi-disciplinary approaches was employed, including cross-sectional and longitudinal laboratory based studies of physical measures, epidemiological studies of anthropometric and biochemical variables, and retrospective questionnaire studies based on reported information. Details of methodologies will be described in each chapter.

To answer all the research questions, a large database was needed, which was not available locally. The epidemiological studies were made possible through international collaboration with the ongoing MORGEN (Bilthoven, The Netherlands) and WHO MONICA (Glasgow, Scotland) projects. The study of waist reduction and cardiovascular risk factors employed data collected in the Aberdeen follow up study of weight loss (Lean *et al*, 1997). In all these cases, raw data had been collected by collaborating researchers, but the analysis were novel and originated from the need to answer hypotheses in the present thesis.

The hypothesis that those with predominant type 2b muscle fibre proportions might be more likely to develop metabolic disorders could not be tested directly, as it would require muscle biopsies and a long term follow up. Instead, a retrospective study was designed using natural ability in sporting performance as presumed marker for muscle composition, relying on the findings of associations of type 1 and type 2 muscle fibre predominance with endurance and power athletes respectively (Åstrand and Rodahl, 1986), to relate to cardiovascular disorders. The subjects recruitment was conducted in collaboration with the Army School of Physical Training (Aldershot, England) in order to maintain anonymity of the former soldiers.

In a cross-sectional study, 1189 subjects were recruited specifically in Glasgow, to investigate the associations of altered body proportion in adults (used as presumed makers for the effects of poor nutrition at different time of early intra-uterine growth) to relate to coronary heart disease and predisposing risk factors.

2.3 Statistical considerations for experimental designs in research

Starting a research study requires careful plans in experimental design to recognise and minimise potential error and bias, in order to infer correctly and interpret the results with confidence. This section addresses some of the fundamental considerations for the development of protocols for scientific studies, and then relates these issues to the work in the present thesis.

2.3.1. Measurement error

The reason for recruiting more than one subject in experiments is that there will be differences between individuals for any measurable characteristic, or response to an intervention, and all measurements have a range of error attached. Measurement error can be minimised by increasing precision to reduce random error, which includes sampling error. The primary way to reduce random errors is by increasing sample size. Another way of minimising random error is by increasing validity to reduce systematic error: inferences to actual subjects in the study (internal validity) and to subjects outside the study (external validity). With respect to internal validity, selection bias, information bias and confounding play a role.

Subject selection

Methods of subject recruitment depend on the questions asked to test the hypothesis raised, and the distribution and variability of variable of interest. In practice, we are normally limited to subjects who are easily available to us. This may have an effect on the outcome of the experiment. The lower the variability between the subjects is, the better chance we have of detecting a treatment difference if it exists. Although it is helpful to restrict to a particular subset for uniformity, it may lead to difficulties, for example a treatment may be effective in one group, but not in others. When human subjects are involved, study design becomes important for ethical reasons to avoid wasting time, resources and goodwill in projects based on inappropriate aims or methods.

Random Sampling

Random sampling is required to ensure the subjects are representative of the population, to eliminate biases such as volunteer bias. There are several methods for sampling including the simple random sampling from a table of random sampling numbers (Fisher and Yates, 1974) which will be representative provided it is large enough. Stratified random sampling in sections of populations uses identifiable categories such as age, sex, race, geographic area, demographic and lifestyle factors, to ensure that the sample represents these aspects within the general population.

It has to be recognised that volunteer subjects may have some unusual qualities such that they are not entirely representative of the general population.

Sample size

The larger the sample size, the closer it reflects the 'true' population (Kline, 1954), but limits must be set in most laboratory based experiments due to the time and the costs. Excessive sample sizes also expose unnecessary numbers of subjects to the research and thus become unethical. To obtain a minimum sample size for a study, the statistical power must be set, and the number calculated for determining the differences that the study aims to detect or exclude. This calculation requires some estimate of the variability in measurement of the variable of interest, either through experience or pilot tests. The sample size therefore depends on the standard error of the variable to be estimated including biological variability, measurement error and random errors (Kahn and Sempos, 1989). In human studies, the size of the sample recruited must allow for the potential rates of response and drop out. In practice, original research often addresses topics where in formation necessary for a formal power estimation is not available, and reasonable assumption have to be made.

Controls

Controls are required to eliminate the influence of as many confounding factors as possible. A common method used in cross-sectional research is matched pair control. For intervention studies, treatment and control group recruited from the same population should be randomly allocated. A cross-over design is often used in longitudinal studies being highly economical in numbers of subjects, but parallel control method avoids the need for a washout period and carry-over effects, and it also reduces problems related to subject fatigue. Studies using controls allow better assessment of the effectiveness of treatment on the variable of interest. There are several ways of designing controls. One way is just not to give the treatment to the control subjects, the other is to give them a placebo treatment (e.g. a dummy pill) so that the 'placebo effects', in which the potential response from the physical appearance or taste *etc.* of taking the pill, can be eliminated, and so the 'true effect' of the treatment can be obtained.

An internal control group, e.g. bottom tertile of a variable can be used as the reference group to look for explanatory factors in a high tertile group. To avoid bias from *post hoc* stratification of the sample, this type of analysis needs to be planned in advance.

Repeatability, accuracy and precision

The results of a study must be reproducible within reasonable limits of errors. Factors within this are that the method of measurements should be accurate and precise. The accuracy of a method is a function of its ability to yield results that are close to the true value. An accurate result provides specific and unbiased results. The precision of a method is related to its ability to provide the same result every time. A precise method yields small 'spread' of observed repeated measurements made on one specimen. A precise (highly repeatable) method is not necessarily accurate (close to the true measurement). To assess the validity, the results must be tested in an independent sample, and cross-validated to assess for potential biological bias. The Bland and Altman (1986) method offers a useful way to compare two methods by assessing accuracy and bias.

2.3.2 *Sensitivity, specificity, and predictive values*

A good method used to screen subjects with a particular health risk would ideally have high sensitivity and specificity. High sensitivity correctly identifies most people with the disease, and high specificity correctly identifies most people without the disease. Because no test is perfect, and the distributions of sensitivity and specificity normally overlap each other in disease and non-disease populations, the two tests cannot both reach 100% at a single point. Receiver operating characteristic (ROC) analysis can be used to identify the level where maximum mean value of sensitivity plus specificity occurs. The level can be defined based on the trade-offs between misclassification and resources *etc*. A screening test should be cheap and simple, relatively non-invasive, provides acceptable sensitivity and specificity, used where screening has practical value. Values of positive prediction (percentage of positive results that are true positive) and negative prediction (percentage of negative results that are true negative) test results are used to assess the diagnostic value of the results of the tests. A test with high sensitivity may yield low positive prediction if the prevalence of the disease of interest is low.

2.4 Study designs in the present thesis

Cross-sectional population survey

In the MORGEN study, a stratified random sampling method was used to recruit subjects, by sampling randomly from civil registries from Amsterdam, Maastricht, and Doetinchem. To obtain similar numbers of subjects at each age, the recruitment was stratified by sex and five year age group. The numbers were planned to be analysed by tertiles, but not large enough to be divided by quintiles for most outcome variables. Longitudinal follow up is underway, but was not available for analysis in the present thesis. When the prevalence of outcome variable increases, analysis in smaller groups (e.g. quintiles) will be possible.

In the body composition studies, an opportunistic approach was used to select volunteers to match the general population profile (Gregory *et al*, 1990; Bennett *et al*, 1995) in terms of age, sex, height, weight and fat distribution. Using this approach, the risks of bias from a non-randomised recruitment are reduced when the range and distribution of variables of interest match those in a random sample.

Retrospective follow up study

In the study of early natural sporting ability in relation to metabolic disorders in later life in former British soldiers, subjects were selected as a population of interest because of their probable relative homogeneity in terms of health, fitness, dietary and other lifestyle behaviours at the same age. Subjects were surveyed using postal questionnaires to determine to recalled determinants. The numbers of subjects recruited were based on a pilot study to determine the response rate and the incidence of the disease of interest. It was considered that recall bias in birth weight, medical history, and natural ability in sport type would be unlikely to confound analysis by explanatory variables of interest.

Diet intervention

A randomised cross-over design was used in a study of overweight volunteers in the study of waist reduction and improvement in cardiovascular risk factors. All subjects were treated with moderately low calorie diets, with one group receiving high, and the other low proportion of energy from carbohydrate for three months. Each subject group receiving the alternative diet for a second three month period. The numbers of subjects and statistical power to detect the differences were determined prior to the trial. The main sources of bias may come from the volunteers' self interest in weight loss studies and expectation of the diets.

Follow up study

In the study of the effectiveness of the Waist Watcher tape measure in weight management, one group of subjects received the tape and dietary and exercise recommendations, and the other, serving as control, received nothing. Subjects were recruited by stratified random sampling from a random sample of 1800 subjects who participated in the MONICA 4 project one year previously, based on age, sex, and waist circumference. Quota sampling method was used in order to assign approximately equal number in each cell.

2.5 Statistical methods applied in data analyses in the present thesis

In the present thesis, a variety of statistical methods were employed to analyse the data, with the aid of computer software including SPSS (Version 6, Chicago, USA) and SAS (version 6.1, Cary, USA). Specific statistical handling is described in each section.

Data summary and presentation

Information of data collected was examined by calculating numbers from the data (statistics). There were three types of data: qualitative data, e.g. sex, discrete quantitative data, e.g. number of people in a household, and continuous quantitative data, e.g. weight. Data were summarised to examine the frequency distributions. The average of the sample was presented as mean, and the measures of dispersion were presented as standard deviation and range. The summary extracted from the data were presented in the form of tables and graphs to convey information.

Measures of association

The present thesis used (multiple) linear regression, for continuous dependent variables, and (multiple) logistic regression analyses, for dichotomous dependent variables, to determine the associations between variables, presented as regression coefficients and odds ratios, respectively. Standard error and 95% confidence interval of the samples were calculated to determine the precision of the estimates of the populations from which they were drawn. Analyses of residuals from multiple linear regression were used to determine the relative contribution of individual variables which correlated closely to each other, e.g. body mass index, waist circumference and hip circumference.

Comparing data

Differences between groups were compared using chi-square tests, and t-tests. Where two methods of measurements were being compared, an adopted Bland and Altman (1986) method was used to estimate the magnitude of errors and biases at extreme ends of measurements, and to examine systematic differences between methods. These differences were plotted against factors such as age and other biological measurements to examine possible bias.

Sensitivity and specificity, and predictive values

The sensitivities and specificities were calculated to evaluate the performance of the test methods to identify the number of subjects with health risks, and those without a risk. The positive and negative prediction values were calculated to assess the results of the tests. Analyses of receiver operating characteristics (ROC) were performed to determine an 'optimal' cut-off point that identified the maximum numbers of those with risk (sensitivity) and the maximum numbers of those without a risk (specificity).

|| CHAPTER THREE

ASSESSING AND DEVELOPING METHODS OF BODY COMPOSITION MEASUREMENTS

|| CONTENTS OF CHAPTER THREE — PAGES

— 3.1 —

PREDICTING BODY COMPOSITION BY BODY DENSITY FROM SIMPLE ANTHROPOMETRIC MEASUREMENTS

This section has been peer reviewed and has been published as

Lean MEJ, **Han TS**, Deurenberg P. Predicting body composition by densitometry from simple anthropometric measurements. *American Journal of Clinical Nutrition* 1996; **63**:4-14.

ABSTRACT

New equations have been developed to predict body fat (percent BF) calculated from body density measured by underwater weighing from simple anthropometric measurements, using stepwise multiple regression analysis in 63 men and 84 women. Log_{10} sum of 4 skinfold thicknesses explained 80.1% (SE = 3.8) of variance of percent BF in men and 76.4% (SE = 4.6) in women. Alternative equations using limb lengths instead of height may be valuable for epidemiological and clinical work, with particular advantages for the very overweight and the chair- or bed-bound for whom no previous predictive equations existed. Five equations combining triceps skinfold thickness with other anthropometric measurements explained >80% (men) and 77% (women) of variance. The most powerful prediction was from waist circumference and triceps skinfold thickness, which explained 86.6% (SE = 3.2) of variance of percent BF in men and 79.0% (SE = 4.0) in women. Percent BF for men = 0.353 × waist (cm) + 0.756 triceps (mm) + 0.235 × age (years) - 26.4; for women = 0.232 × waist (cm) + 0.657 × triceps (mm) + 0.215 × age (years) - 5.5. The equations were tested in a separately studied validation sample of 146 men and 238 women aged 18-83 years. Skinfold thickness measurements continued to give good predictions of mean body density, but with significant bias at extremes of body fat and of age. The most robust prediction with least bias was from waist circumference adjusted for age. Percent BF for men = 0.567 × waist (cm) + 0.101 × age (years) - 31.8; and for women = 0.439 × waist (cm) + 0.221 × age (years) - 9.4.

Keywords: anthropometry, body composition, body mass index, fat distribution

INTRODUCTION

Many techniques have been developed to assess body composition in humans. Direct measurement by chemical analysis, either by macroscopic dissection or by lipid extraction is of limited value as it cannot be done *in vivo*. The conventional standard is underwater weighing (UWW) for a two-compartment model, which measures body density from which fat and lean mass content are estimated assuming standard figures for density of these components (Siri, 1961). Other robust methods include the total body potassium method, measuring intracellular fluid by detecting the natural radioactive ^{40}K isotope (Boddy *et al*, 1972), and measurement of the total body water by dilution of a deuterium-labelled water dose (Schoeller, 1980). The principles for these techniques are described in detail by Brodie (1980), Garrow (1983), Gibson (1990) and Shephard (1991). More complicated multi-compartment models of body composition including bone mass are under development.

For routine clinical and epidemiological use, simpler and cheaper anthropometric measurements have been used to predict body composition in relation to body density by UWW. Various combinations of anthropometric measurements have been used as independent variables. Shephard (1991) reviewed the extensive literature and found few truly practical anthropometric approaches to predict body density or fat content. The most widely used method, that of Durnin and Womersley (1974) used the log sum of four skinfold thicknesses to develop regression equations for males and females of different age groups. Jackson and Pollock (1978) and Jackson *et al* (1980) used the sum of three or seven skinfold thicknesses in combination with waist and forearm circumferences or gluteal circumference and age for generalised regression equations. These approaches have not been subjected to systematic validation in separate samples or populations. Recently, Deurenberg *et al* (1991) suggested that body mass index (BMI) with age and sex can predict body density with an accuracy similar to that of skinfold methods in a large sample of Dutch population. McNeill *et al* (1991) observed skinfold-thickness method to be as good as bioelectrical impedance, body water dilution, and better than ^{40}K counting methods relating to UWW in lean and overweight groups of women. Reilly *et al* (1994) found the skinfold-thickness method to underestimate body fat in small sample (n = 16) of 65-79 year old women.

The present study was designed to develop regression equations from different combinations of simple anthropometric measurements, age, and sex to obtain the best equations to predict body density from UWW. Recognising possible errors from the influence of fat distribution on prediction of body composition (Lean and Mann, 1991) from the conventional skinfold-thickness method of Durnin and Womersley (1974), we included waist and hip circumferential measurements, because waist (Han *et al*, 1995a; Pouliot *et al*, 1994; Ross *et al*, 1992; Ross *et al*, 1993; Seidell *et al*, 1989) or waist to hip ratio (Han *et al*, 1995a; Pouliot *et al*, 1994) has been found to correlate with the ratio of visceral to subcutaneous fat. Alternative methods were considered for very obese subjects, i.e. BMI >37 kg/m^2, whose skinfold thicknesses exceed the size of the calipers, or where the use of skinfolds is inconvenient or unacceptable, and arm span and lower leg length were considered for subjects whose height cannot be measured. The equations developed were then tested in a validation study employing a large data set obtained in a different population.

METHODS

1. Determination study (Glasgow)

Subjects and recruitment

Ethical approval was obtained from Glasgow Royal Infirmary's Ethical Committee. Healthy adult white volunteers (63 men and 84 women) were recruited from Greater Glasgow area by local advertisement. Volunteers with known diabetes were not included. Physical characteristics of subjects are shown in **Table 3.1.1**. Subjects were recruited to provide an even distribution by age (**Figure 3.1.1**), but not selected for any other criteria.

Measurements of subjects were made in the morning after overnight fasting, with an empty bladder, wearing a swimsuit. All measurements were made by the same investigator in every subject, thus $n = 147$, or 63 for men, 84 for women in all analyses.

Densitometry by underwater weighing

A metal chair was suspended in a hydrotherapy pool, attached to a strain gauge (Mecmesin Ltd, Horsham, England) with a ±20-kg range, and sensitivity to 0.01 kg. Subjects sat in the chair, with water up to their necks, holding the arm-rests of the chair and with their feet on a bar attached to the chair. Their noses were sealed by a nose clip. In full expiration, subjects gently lowered their head under water. Weight was recorded using a pen recorder that was calibrated with known weights.

Residual lung volume

The residual lung volume was measured simultaneously with UWW by the three-breath-nitrogen technique modified from Womersley (1974). Four 6-litre anaesthetic bags (Ohmeda plc, Hatfield, UK) were filled with a known volume of 100% oxygen measured by a dry rolling seal spirometer (PK Morgan, Kent, UK), about 3 litres for women and 4 litres for men (Wilmore *et al*, 1980). On raising their heads from under water, a 35-ml mouth piece connected to an anaesthetic bag was inserted into the subject's mouth. Subjects then breathed in and out deeply three times. After the last complete expiration, the bag was sealed and the gas mix obtained was immediately analysed for oxygen (Polarographic, PK Morgan, Kent, United Kingdom) and carbon dioxide (Infra-red, PK Morgan, Kent, UK) content. Nitrogen content (%N) of the gas mix was calculated from differences in oxygen (%O_2) and carbon dioxide (%CO_2): $(\%N = 100\% - \%O_2 - \%CO_2)$. Residual volume (RV) was calculated as:

$$RV = F \times \frac{N \times (V + 0.035l)}{80\% - N\%},$$

where V is the initial volume of 100% oxygen in the gas bag, 0.035 l is the volume of the dead space in the mouth piece, with nitrogen content of the alveoli air before the test assumed to be 80%, and a correction factor (F) was included for standard temperature and pressure in dry condition (STPD):

$$F = \frac{273 + T_b}{273 + T_g} \times \frac{P_{atm} - P_s}{P_{atm} - P_A},$$

where T_b and T_g are the temperature of body (37 °C) and gas in the spirometer respectively, P_{atm} is atmospheric pressure, P_A and P_s are saturated vapour pressure of water in the lungs (assumed to be 47.1 mmHg) and spirometer (assumed to be 18.63 mmHg) respectively (Womersley, 1974).

Subjects were first allowed to practise the techniques for holding breath, bending down and up, and breathing to the mouth-piece adequately outside the pool. They also practised in the water to familiarise themselves with the environment. Finally, measurements were made after allowing the water to become absolutely calm. The temperature of the pool was kept at exactly 36.5 °C throughout the studies.

Anthropometry

Height was measured with the subject standing, back to stadiometer, in bare feet. The head was adjusted so that the Frankfurt plane (the line from the auditory meatus to the lower border of the eye orbit) was horizontal. Feet were kept parallel with the heels together. The subject was encouraged to stretch upwards by applying gentle pressure at the mastoid processes (Gibson, 1990). The moving arm of the stadiometer was lowered to touch the top of the head and height was measured to the nearest 1 mm.

Arm span was measured from the distance between the tips of the longest fingers in each hand, with arms stretched horizontally while in standing position and with the back against a wall. Lower leg length was taken from the mean of the two legs. The subject sat in a chair, with bare feet, and lower legs vertical and parallel. Lower leg length was measured as the distance between the floor and the top of the patella.

Weight was measured to the nearest 0.05 kg by a beam balance, which was calibrated daily using ten 8 kg test weights. Waist, hip, thigh, and mid-upper arm circumferences (MUAC) and skinfold thicknesses were made with subjects standing, with intended sites marked on the skin, except hip and thigh circumferences. A flexible steel tape was used (Holtain Ltd, Crymych, UK). All measurements were made twice, and the mean was used in regression equations. Waist circumference was measured midway between the lateral lower ribs and iliac crests (WHO, 1989). Subjects were asked not to tuck the stomach in, and the measurement was taken in gentle expiration. Their clothes were loosened around the waist area. Hip circumference was taken at the widest part over the trochanters. Feet were kept 25 to 30 cm apart, (WHO, 1989). Thigh circumference was measured for both legs 2 cm below the gluteal fold, with the weight on the non-measured leg, i.e. the leg being measured relaxed. The average of the two legs was used in regression equations.

MUAC was measured on the right arm at the midpoint between the tip of the acromion and the tip of olecranon, elbow bent at 90°. Four skinfold thicknesses were measured according to the protocol described by Durnin and Womersley (1974). All measurements were made on the right side of the body with calipers (Holtain Ltd, Crymych, UK). Biceps and triceps skinfold thicknesses were taken at the midpoint (*see* MUAC) of the upper arm. Subscapular skinfold thickness was measured with subject's shoulders relaxed. The measurement of supra-iliac skinfold thickness was taken with the subject breathing gently. In some obese subjects whose skinfold thickness exceeded the range of the calipers (50 mm), an estimate was made with a ruler.

Statistics

Data were analysed using the MINITAB statistical programme (Clecom, Birmingham, UK). Linear regression equations were developed using stepwise multiple regression analysis. Body density by UWW was used as the dependent (response) variable, anthropometric measurements and age used as independent (explanatory) variables for men and women separately.

Measurements of UWW and residual lung volume were made three times for each subject, and twice for body circumferences and the mean taken. The experiment was repeated if the CV for the repeated measurements was >1%. The SD of repeated measurements on the same subject was calculated by the equation given by Bland (1987): $SD = \sqrt{1/2n \times \sum(x_i - y_i)^2}$, where x_i and y_i are pairs of measurements for $i = 1$ to n. The CV was calculated as SD/overall mean.

2. Validation study (Wageningen)

Data were made available from earlier studies by Deurenberg *et al* (1991) from 146 men and 238 women, including body density measured by UWW with residual volume estimated by simultaneous helium dilution; waist and hip circumferences; biceps; triceps; subscapular and suprailiac skinfold thicknesses; weight; height, age; and sex. Anthropometric measurements used the same protocols as in the present study except that skinfold-thickness measurements were made on the left. This sample was used as an independent population to test the validity of the equations derived from the Glasgow determination study. Measurements of arm span, lower leg length, and MUAC were not available in the validation sample. Skinfold-thickness measurements were available in 143 men and 236 women.

Statistics

The Bland and Altman analysis (Bland and Altman, 1986) used to assess the mean and 95% CIs of errors of body fat prediction as the difference in percent body fat estimated by regression equations from percent body fat measured by the reference UWW method.

RESULTS

1. Determination study

Details of subjects and the anthropometric data are given as mean ±SD in **Table 3.1.1**. Sixty-three males aged 17-65 years and 84 females aged 18-64 years were studied under standard fasting conditions, with even distributions over wide ranges of weight, BMI, waist circumference, waist to hip ratio, skinfold thicknesses and body density. The mean height, weight and BMI were similar to average figures in the British adult population (Gregory *et al*, 1990).

Diurnal variations were studied for certain measurements made in the morning fasting and then in late afternoon for weight in 15 men, mean age 25 (range 20 to 46 years) and 35 women, mean age 25 (range 21 to 35) years, and height of 65 men, mean age 42.3 years (range: 16.8-65.4) and 69 women, mean age 43.1 years (range: 22.3-70.7). On average, there was a significant increase in body weight, mean +0.26 kg (95% CI: 0.16 to 0.35, $P < 0.05$) and a decrease in height, mean -0.8 cm (95% CI: -1.0 to -0.6, $P < 0.001$) in the afternoon compared with the morning. These effects are compounded in estimates of BMI so on average, BMI (weight/height^2) would increase by 0.3 kg/m^2 (1.2%) during the day. The CVs for repeated measurements of UWW, and waist and hip circumferences were 0.16%, 0.44% and 0.20% respectively.

Figure 3.1.1a shows the age distribution, separately for men and women, in relation to body density. In general, body density decreased with increasing age. Females had consistently lower body density than males at a given age.

A plot between body density and waist circumference **(Figure 3.1.1b)** demonstrates an almost linear relationship (men: r = -0.88 and women: r = -0.79). Both men and women showed approximately the same gradient, with lower intercept in females. For a given waist circumference, the women tended to be less dense (fatter) than men, reflecting the greater central (visceral) fat deposition in men. Waist to hip ratio gave good prediction in men, but no better than waist circumference alone.

A plot between body density and triceps skinfold thickness (**Figure 3.1.1c**) shows the regression lines for males and females almost shared an identical intercept and slope, suggesting triceps skinfold thickness reflects proportionally the same amount of fat for the two sexes. Men tended to be leaner with smaller triceps skinfold thickness (10.9 ±4.6 mm) than women (19.1 ±5.4 mm).

Linear regression: single variables

Table 3.1.2 shows the 17 significant ($P < 0.001$) correlations between body density and single anthropometric variables for men and women. Body density correlated most closely with waist circumference in both sexes (r = -0.88 in men and -0.79 in women). Thigh circumference correlated only moderately with body density, slightly higher in women (r = -0.58) than in men (r = -0.53). Correlation coefficients between body density and individual skinfolds ranged from -0.61 to -0.76 in men and from -0.66 to -0.77 in women. The sum of four skinfold thicknesses correlated with body density more closely than single or combinations of two or three skinfolds in men (r = -0.772) but not in women (r = -0.763). A search was made for a better nonlinear relation (quadratic or logarithmic transformation), but no improvement in r^2 or SE was found, except for the relation with skinfold thicknesses. As in the study of Durnin and Womersley (1974) logarithmic transformation of the sum of four skinfold thicknesses increased the correlations significantly ($P < 0.05$) with body density in both men (r = -0.81) and women (r = -0.78).

Stepwise multiple regression analysis

When all 20 anthropometric measurements or selected ratios (**Table 3.1.2**) were considered separately for each sex as possible explanatory variables, the best prediction (highest r^2) of body density for men was Waist circumference + Triceps skinfold thickness + Age. This equation accounted for 86.6% of variance of body density. The best prediction of body density in women was from BMI + Triceps skinfold thickness + Age, explaining 80.2% of variance, but this equation was only slightly better than other simple equations, which included Waist circumference + Triceps SF + Age (r^2 = 79.0%). Other anthropometric variables combining with triceps skinfold thickness also gave good prediction of body density explaining >76.0% of variance (**Table 3.1.3**). Log_{10}

sum of four skinfold thicknesses ($\log_{10}\Sigma_4$SF) gave a similar power of prediction of body density in the present study (men: r^2 = 80.1 %; women: r^2 = 76.4%) to the published equations (highest r^2 value of 81%) of Durnin and Womersley (1974).

Figures 3.1.2a-d show the relationships between the observed body density and predicted body density from some selected anthropometric variables. **Tables 3.1.4** and **3.1.5** contain six pairs of regression equations (numbers 1-6) validated in the Wageningen study to predict body density and equivalent percent body fat estimated from Siri's equation (1961): Percent body fat = (4.95/body density - 4.5) × 100%.

For subjects whose height cannot be measured, arm span and lower leg length were considered as alternatives. Height correlated with arm span (men: r = 0.76 and women: r = 0.81) and lower leg length (r = 0.85 for both men and women). These variables gave prediction of body fat as good as other commonly used variables (**Table 3.1.3**). Equations 7-12 incorporating these variables which could not be validated in the Wageningen validation study.

2. Validation study

Subjects in the validation sample had wider range of ages (18-83 years) than the determination study. Both samples had similar BMIs but the validation sample was fatter and had higher waist circumference and waist to hip ratio, indicating an accumulation of abdominal fat mass associated with older subjects in this sample (**Table 3.1.6**).

Percentage body fat was predicted by equations 1-6 derived from the determination study, and by that of Durnin and Womersley (1974) for comparison. The prediction errors of each equation were calculated from the difference between predicted body fat and body fat measured by UWW.

Table 3.1.7 shows the mean body fat of the Wageningen validation sample predicted by equations derived from the Glasgow determination study correlated highly (r >0.82; P <0.001) with body fat by UWW. The mean difference (prediction errors) with its SE and SD for each of the derived equations and those of Durnin and Womersley (1974) were similar, ranging from 4 to 5% of body weight, i.e., 95% CI limits for errors of 8 to 10% of body weight about the mean errors. Body fat prediction from triceps skinfold thickness in men gave the worst SD of 6.6% of body weight (95% CI limits of error: 13% of body weight). Although the mean errors of all equations were close to zero, almost all equations had significant positive or negative slopes for a plot of errors relative to body fat measured by the reference UWW method. This indicates systematic errors or bias in predicting body fat in individuals at extreme ends of body fat spectrum **(Table 3.1.8)**. Densitometry makes an assumption the fat free mass has a constant density of about 1.1 kg/l (Siri, 1961); error in the reference method may relate to the possibility that the density of fat free mass is lower than this in the obese subjects, and higher than this in the very thin subjects because of different relative contribution of the organs (Shephard, 1991).

Using waist circumference alone, adjusted for age, gave equally good prediction of body fat, with similar SE and SD to other equations using more than one variable or measurement, including the Durnin and Womersley equations **(Figures 3.1.3a-f)**. The mean errors were close to zero in both men (-0.95 % of body weight) and women (-0.93 % of body weight), with a negative slope of errors almost identical to those found using Durnin and Womersley equations for men **(Figure 3.1.3c)**. The slope was less steep for women **(Figure 3.1.3f)** indicating that body fat is less likely to be underestimated in fatter subjects using the waist circumference equations than those from Durnin and Womersley.

All equations containing triceps-skinfold measurement, including those from Durnin and Womersley had significant positive or negative slopes for a plot of errors in predicting body fat against age **(Table 3.1.9)**. Negative slopes were observed for predicting errors with increasing age by Durnin and Womersley (1974) equations, but there was no systematic bias in percent body fat prediction with age using waist equations in both sexes (**Figures 3.1.4a & b**). The mean and 95% CIs of errors of percent body fat prediction in different age groups are presented in **Table 3.1.10** showed that the skinfold-thickness method (Durnin and Womersley, 1974) gave good prediction of percent body fat in younger subjects (age <60 years), but underestimated percent body fat of subjects aged 60-83 years up to 15% of body weight, whereas the waist circumference equations from the present study continued to give good prediction of percent body fat in 60 -83 years.

DISCUSSION

The present study has examined all the simple anthropometric measures currently in use, in predicting body density to estimate percentage body fat. The numbers of subjects (63 men and 84 women) studied met the minimal number (n = 50) for generating prediction equations, recommended by Katch (1985), and allowed power of prediction at least equal power to those currently employed. The age distribution of subjects permits confidence over a wide range of ages. The validation sample had been studied under similar rigorous conditions, but by other observers and in an entirely different white population.

The equations from the present study were derived from a healthy white population broadly representative of the UK adult population, including very few athletes or unusually thin individuals. Barata *et al* (1993) recently found the equation of Jackson and Pollock (1978) better than those of Durnin and Womersley (1974) for athletes. Caution should be exercised when applying the equations to other population groups, or to subgroups with unusual physical characteristics.

Stepwise multiple regression analysis for the combination of single measurements found waist circumference and triceps skinfold thickness, together with age, to provide the best prediction (highest r^2) of body density, explaining 86.6% and 79% of variance in men and women, respectively, in the population from which the equations were derived. This equation applied less well in the validation study, which probably reflects differences between observers in triceps skinfold-thickness measurements. The prediction of body density from waist measurement alone, corrected for age (**Table 3.1.3**), is remarkably good (men: r^2 = 77.8%; women: r^2 = 70.4%). Age adjusted BMI also showed good prediction of body density(men: r^2 = 67.0%; women: r^2 = 74.5%). Thus, for epidemiological work, both waist circumference and BMI may be useful simple measurements. Several other combinations of body circumferences and skinfold thicknesses (biceps, triceps, subscapular, suprailiac) also gave good correlation with body density, but no better than the combination of waist circumference and triceps skinfold thickness. Age and triceps skinfold thickness combined with BMI, the ratios of body mass to arm span or body mass lower leg length gave similar prediction power for body density in both sexes. The classical equation of Durnin and Womersley (1974) using $\log_{10}\Sigma_4$SF still gives a useful prediction, but BMI (with age and sex corrections) also demonstrated high predictive value (r^2 = 80.0%; not shown in tables) for body density, confirming previous observations from Deurenberg *et al* (1991). Equations with BMI + Triceps skinfold thickness gave better predictions of body density (men: r^2 = 84.5%; women: r^2 = 80.2%) than did $\log_{10}\Sigma_4$SF. The best four equations obtained from stepwise multiple regression analysis in the Glasgow determination study, which all included triceps skinfold thickness measurement and either waist circumference or body mass, were significantly more powerful ($P < 0.05$) than $\log_{10}\Sigma_4$SF prediction equations in the population used to derive them.

A major advantage of waist circumference and triceps skinfold-thickness methods lies in their practical use (**Tables 3.1.4** and **3.1.5**). The four skinfold method requires a little practice to be reproducible, and may present some difficulties when subjects are clothed, or when skinfold thickness exceeds 50 mm (the limit of the calipers). This eliminates mainly obese subjects. With BMI above 37 kg/m^2, subscapular and supra-iliac skinfolds usually exceed 50 mm and can only be roughly estimated.

The equations based on Waist circumference + Triceps skinfold thickness offer another advantage over skinfold only methods by taking account of body fat distribution. For example, people with heart disease and with non insulin dependent diabetes mellitus have exaggerated central (visceral) fat distribution (Björntorp, 1985). In subjects with the highest quartile of waist to hip ratio including subjects with diabetes, we have found that equations using waist circumference are significantly better than methods based on subcutaneous skinfold thicknesses or BMI (Han and Lean, 1994). Waist circumference reflects intra-abdominal fat, as distinct from the subcutaneous fat which is reflected in triceps measurement, although both reflect total fat as well. Magnetic resonance imaging (Han *et al*, 1995a; Ross *et al*, 1992; Ross *et al*, 1993) and computerised tomograhy studies (Pouliot *et al*, 1994; Seidell *et al*, 1989) showed that waist circumference correlated with fat from all sites, including intra-abdominal fat (r range 0.73-0.94; $P < 0.001$) and total body fat ($r > 0.94$; $P < 0.001$) in both men and women, although triceps skinfold thickness correlated highly with subcutaneous fat (r range 0.69-0.89; $P < 0.05$) and poorly with intra-abdominal fat ($r = 0.39$; P = not significant) in both men and women.

Equations using the simple measurement of waist circumference and age proved to be remarkably robust for body fat prediction, as good as the existing method of combining 4 skinfolds in men and better in fatter women where the Durnin and Womersley systematically underestimates body fat. **Figures 3.1.3c & f** suggest some bias in predicting body fat with increasing body fatness. Measurement of residual lung volume by helium in Wageningen and nitrogen in Glasgow were the only methodologic difference, but this does not readily explain any bias. An alternative explanation for the bias could be the difference in body fat distribution in the Dutch population, possibly related to physical activity, smoking, and alcohol consumption. These equations based on waist circumference (**Tables 3.1.4a** and **3.1.5a**; equation 1) are also applicable to older subjects without the systematic underestimation of body fat shown by the four-skinfold method. This bias may indicate altered density in lean body mass with age

(Reilly *et al*, 1994), but there is little independent evidence for altered lean body mass in elderly people. Altered body fat distribution with aging is a more plausible explanation, which is taken into account by the waist circumference method.

Waist measurement is the a highly practical method and its percentage measurement error is low due to its large circumference. Only a flexible tape is required, with minimal training to use bony landmarks. The only drawback would be in the very obese (BMI >45 kg/m^2) when a large apron of abdominal fat would invalidate waist measurement. When waist circumference and skinfold measurements are not available, BMI from body mass and height could be used as alternative method to predict body fat. The bias could be from one of the UWW protocols. The Glasgow method was tested against the earlier Durnin and Womersley tank as its replacement, showing no difference between the two methods on the same subjects. The Wageningen has been well established and has been used in many published studies (Deurenberg *et al*, 1991). Because of their distance from one another, the Glasgow and Wageningen UWW methods cannot be compared directly.

Alternatives to BMI were developed using the ratios of body mass over arm span in kg/cm or lower leg length in kg/cm. These indices were analysed with other single anthropometric variables adjusted for age and sex. The best equations obtained were for the ratios of body mass to arm span ($r^2 = 80.0\%$), and body mass to lower leg length ($r^2 = 79.3\%$). There was no significant difference when various powers were applied to variables. Triceps skinfold thickness was added to these equations (separate sexes) resulting in similar improvement for the prediction of body density as other multiple regression equations, for the ratios of body mass to arm span, $r^2 = 84.4\%$ (men) and 79.9% (women) and body mass to lower leg length, $r^2 = 83.5\%$ (men) and 79.3% (women). These equations may be of value for the elderly, chair-bound and bedridden subjects, and use of lower leg length instead of height may occasionally be helpful clinically and in field work. To keep errors to a minimum in routine use, training of observers is urged, even for simple procedures.

CONCLUSIONS

The twelve equations for each sex group (**Tables 3.1.4** and **3.1.5**) use simple anthropometric measurements to predict body composition. All equations, except mid-upper arm circumference in men, gave acceptable accuracy and low error of prediction (**Table 3.1.3**), and thus can be used for clinical and epidemiological purposes. The time, equipment, and skill required for these measurements vary. An equation using waist circumference adjusted for age, as well as giving a prediction with low error and freedom from bias with age or fatness, is also amongst the most convenient and avoids errors associated with altered fat distribution. Log sum of four skinfold thicknesses still gives very acceptable prediction of body composition, but with some underestimation in elderly subjects and in fat women, and BMI can be used satisfactorily when these measures are unavailable. The most powerful prediction of body fat, from waist circumference and triceps skinfold thickness performed less well in a validation sample, and is probably dependent on individual technique of triceps skinfold thickness measurement. For the elderly, chair-bound and those with amputations, arm span or lower leg length can be used instead of height.

Table 3.1.1. Characteristics of men and women in the determination study.

	Men ($n = 63$)			Women ($n = 84$)		
	Mean	SD	Range	Mean	SD	Range
Age (years)	40.1	13.1	16.8-65.4	39.9	14.1	18.0-64.3
Height (m)	1.75	0.06	1.61-1.87	1.62	0.06	1.43-1.78
Weight (kg)	76.5	13.1	58.8-128.4	65.4	11.9	46.1-97.3
Body mass index (kg/m^2)	24.9	4.3	18.9-41.2	24.9	4.3	18.3-37.7
Waist circumference (cm)	88.1	12.5	68.7-129.1	78.3	11.8	60.4-116.1
Hip circumference (cm)	98.0	6.8	87.6-125.5	101.2	9.3	83.8-133.0
Thigh circumference (cm)	55.3	5.1	45.8-70.2	56.6	4.6	49.2-69.9
MUAC (cm)	31.3	3.1	25.9-41.4	29.5	3.8	23.4-43.8
Waist to hip ratio	0.90	0.08	0.77-1.11	0.77	0.08	0.62-0.99
Lower leg length (cm)	53.6	2.2	48.3-57.9	49.6	2.9	40.4-57.6
Armspan (m)	1.76	0.07	1.60-1.90	1.61	0.08	1.40-1.78
Triceps skinfold (mm)	10.9	4.6	3.9-22.7	19.1	5.4	6.1-32.4
$\Sigma_4$skinfold (mm)	51.2	25.7	19.7-161.9	63.2	24.2	23.4-126.1
Body density (kg/l)	1.049	0.023	1.003-1.087	1.024	0.020	0.987-1.061
Body fat (% of body weight)	22.3	8.9	5.2-43.7	33.75	8.7	16.4-51.7

MUAC = mid-upper arm circumference; $\Sigma_4$skinfold = sum of biceps, triceps, subscapular and supra-iliac skinfolds.

Table 3.1.2. Correlation coefficients between body density and anthropometric measurements.

	Men (n = 63)	Women (n = 84)
Age	-0.572***	-0.687***
Height	0.104	0.182
Weight	-0.713***	-0.691***
Body mass index	-0.755***	-0.781***
Waist circumference	-0.878***	-0.790***
Hip circumference	-0.707***	-0.713***
Thigh circumference	-0.531***	-0.575***
Mid-upper arm circumference	-0.586***	-0.790***
Waist to hip ratio	-0.841***	-0.536***
Waist to thigh ratio	-0.714***	-0.570***
Hip to thigh ratio	-0.015	-0.328*
Lower leg length	-0.009	-0.011
Armspan	0.323*	-0.065
MAR	-0.768**	-0.747***
MLR	-0.745**	-0.727***
Biceps skinfold	-0.730***	-0.695***
Triceps skinfold	-0.612***	-0.768***
Subscapular skinfold	-0.678***	-0.661***
Suprailiac skinfold	-0.763***	-0.694***
$\Sigma_4$skinfold	-0.772***	-0.763***
$\text{Log}_{10}\Sigma_4$skinfold	-0.809***	-0.781***

MAR = ratio of body mass to armspan; MLR = ratio of body mass to lower leg length; $\Sigma_4$skinfold = sum of biceps, triceps, subscapular and supra-iliac skinfolds. ***P <0.001; *P <0.05.

Table 3.1.3. Explained variance (r^2) and SEE for predictions of body density and percent BF by regression equations from **Tables 3.1.4** and **3.1.5** and by selected published equations.

Equation	Men (n = 63)			Women (n = 84)		
	r^2 %	SEE kg/l	SEE % body weight	r^2 %	SEE kg/l	SEE % body weight
1. Waist circumference	77.8	0.0092	4.1	70.4	0.0100	4.7
2. Triceps	76.9	0.0094	4.3	75.1	0.0092	4.3
3. BMI	67.0	0.0113	5.0	74.5	0.0093	4.4
4. Waist + Triceps	86.6	0.0072	3.2	79.0	0.0085	4.0
5. BMI + Triceps	84.5	0.0077	3.4	80.2	0.0082	3.9
6. $Log_{10}\Sigma_4$skinfold	80.1	0.0088	4.0	76.4	0.0090	4.2
7. MAR	69.1	0.0109	4.9	73.0	0.0096	4.5
8. MLR	67.7	0.0111	5.0	72.2	0.0097	4.6
9. MUAC	57.3	0.0128	5.8	73.3	0.0095	4.5
10. MAR + Triceps	84.4	0.0077	3.4	79.7	0.0083	3.9
11. MLR + Triceps	83.5	0.0078	3.4	79.3	0.0084	4.0
12. MUAC + Triceps	80.7	0.0084	3.8	77.0	0.0088	4.2
$Log_{10}\Sigma_4$SF (D&W)*	81.0†	0.0084	3.8	81.0†	0.0102	4.6
$Log_{10}\Sigma_7$SF+WC+FC (J&P)*	84.1	0.0073	3.2	—	—	—
$Log_{10}\Sigma_7$SF+GC (J *et al*)*	—	—	—	75.2	0.0079	3.6

Σ_4SF = sum of biceps, triceps, subscapular and supra-iliac skinfolds; MAR = ratio of body mass to armspan; MLR = ratio of body mass to lower leg length; MUAC = mid-upper arm circumference; WC, FC and GC = waist, forearm and gluteal circumferences, respectively. *figures obtained from other published equations are shown for comparison. References: D&W = Durnin and Womersley (1974); J&P = Jackson and Pollock (1978); J *et al* = Jackson *et al* (1980). †highest value quoted. P <0.001 for all equations.

Table 3.1.4a. Regression equations predicting (a) body density (BD) and (b) the equivalent body fat (BF %) in 63 men.

Equation 1. Waist circumference

a) $BD = 1.1674 - (0.00125 \times Waist) - (0.000231 \times Age)$

b) $BF\ \% = (0.567 \times Waist) + (0.101 \times Age) - 31.8$

Equation 2. Triceps skinfold thickness

a) $BD = 1.1181 - (0.00289 \times Triceps) - (0.000953 \times Age)$

b) $BF\ \% = (1.31 \times Triceps) + (0.430 \times Age) - 9.16$

Equation 3. Body mass index (BMI)

a) $BD = 1.1419 - (0.00290 \times BMI) - (0.000527 \times Age)$

b) $BF\ \% = (1.33 \times BMI) + (0.236 \times Age) - 20.2$

Equation 4. Waist circumference and triceps skinfold thickness

a) $BD = 1.1554 - (0.000761 \times Waist) - (0.00170 \times Triceps) - (0.000532 \times Age)$

b) $BF\ \% = (0.353 \times Waist) + (0.756 \times Triceps) + (0.235 \times Age) - 26.4$

Equation 5. Body mass index and triceps skinfold thickness

a) $BD = 1.1414 - (0.00160 \times BMI) - (0.00213 \times Triceps) - (0.000747 \times Age)$

b) $BF\ \% = (0.742 \times BMI) + (0.950 \times Triceps) + (0.335 \times Age) - 20.0$

Equation 6. Log_{10} sum of four skinfold thicknesses

a) $BD = 1.1862 - (0.0684 \times Log_{10}\Sigma_4 skinfold) - (0.000601 \times Age)$

b) $BF\ \% = (30.9 \times Log_{10}\Sigma_4 skinfold) + (0.271 \times Age) - 39.9$

Units of measurements: waist circumference (cm); skinfolds (mm); BMI (kg/m^2); age (years). r^2 and SEE values are given in **Table 3.1.3.**

Table 3.1.4b. Regression equations predicting (a) body density (BD) and (b) the equivalent body fat (BF %) in 63 men.

Equation 7. Ratio of body mass to arm-span (MAR)

a) $BD = 1.1425 - (0.167 \times MAR) - (0.000529 \times Age)$

b) $BF\ \% = (76.7 \times MAR) + (0.237 \times Age) - 20.4$

Equation 8. Ratio of body mass to lower leg length (MLR)

a) $BD = 1.1471 - (0.0530 \times MLR) - (0.000571 \times Age)$

b) $BF\ \% = (24.2 \times MLR) + (0.256 \times Age) - 22.6$

Equation 9. Mid-upper arm circumference (MUAC)

a) $BD = 1.1828 - (0.00333 \times MUAC) - (0.000745 \times Age)$

b) $BF\ \% = (1.52 \times MUAC) + (0.336 \times Age) - 38.7$

Equation 10. MAR and triceps skinfold thickness

a) $BD = 1.1407 - (0.092 \times MAR) - (0.00205 \times Triceps) - (0.000746 \times Age)$

b) $BF\ \% = (42.6 \times MAR) + (0.917 \times Triceps) + (0.334 \times Age) - 19.6$

Equation 11. MLR and triceps skinfold thickness

a) $BD = 1.1423 - (0.0280 \times MLR) - (0.00209 \times Triceps) - (0.000777 \times Age)$

b) $BF\ \% = (13.0 \times MLR) + (0.933 \times Triceps) + (0.348 \times Age) - 20.4$

Equation 12. MUAC and triceps skinfold thickness

a) $BD = 1.1613 - (0.00165 \times MUAC) - (0.00238 \times Triceps) - (0.000882 \times Age)$

b) $BF\ \% = (0.757 \times MUAC) + (1.07 \times Triceps) + (0.398 \times Age) - 29.0$

Units of measurements: MUAC (cm); MAR and MLR (kg/cm); age (years). r^2 and SEE values are given in **Table 3.1.3**.

Table 3.1.5a. Regression equations predicting (a) body density (BD) and (b) the equivalent body fat (BF %) in 84 women.

Equation 1. Waist circumference

a) BD = 1.1145 - (0.000924 × Waist) - (0.000465 × Age)

b) BF % = (0.439 × Waist) + (0.221 × Age) - 9.4

Equation 2. Triceps skinfold thickness

a) BD = 1.0851 - (0.00200 × Triceps) - (0.000586 × Age)

b) BF % = (0.944 × Triceps) + (0.279 × Age) + 4.6

Equation 3. Body mass index (BMI)

a) BD = 1.1088 - (0.00254 × BMI) - (0.000551 × Age)

b) BF % = (1.21 × BMI) + (0.262 × Age) - 6.7

Equation 4. Waist circumference and triceps skinfold thickness

a) BD = 1.1062 - (0.000482 × Waist) - (0.00140 × Triceps) - (0.000453 × Age)

b) BF % = (0.232 × Waist) + (0.657 × Triceps) + (0.215 × Age) - 5.5

Equation 5. Body mass index and triceps skinfold thickness

a) BD = 1.1039 - (0.00148 × BMI) - (0.00122 × Triceps) - (0.000505 × Age)

b) BF % = (0.730 × BMI) + (0.548 × Triceps) + (0.270 × Age) - 5.9

Equation 6. Log_{10} sum of four skinfold thicknesses

a) BD = 1.1622 - (0.0654 × $Log_{10}\Sigma_4$skinfold) - (0.000574 × Age)

b) BF % = (30.8 × $Log_{10}\Sigma_4$skinfold) + (0.274 × Age) - 31.7

Units of measurements: waist circumference (cm); skinfolds (mm); BMI (kg/m^2); age (years). r^2 and SEE values are given in **Table 3.1.3**.

Table 3.1.5b. Regression equations predicting (a) body density (BD) and (b) the equivalent body fat (BF %) in 84 women.

Equation 7. Ratio of body mass to arm-span (MAR)

a) BD = 1.1108 - (0.155 × MAR) - (0.000603 × Age)

b) BF % = (73.6 × MAR) + (0.287 × Age) - 7.6

Equation 7. Ratio of body mass to lower leg length (MLR)

a) BD = 1.1101 - (0.0466 × MLR) - (0.000630 × Age)

b) BF % = (22.0 × MLR) + (0.300 × Age) - 7.2

Equation 9. Mid-upper arm circumference (MUAC)

a) BD = 1.1299 - (0.00291 × MUAC) - (0.000512 × Age)

b) BF % = (1.38 × MUAC) + (0.243 × Age) - 16.7

Equation 10. MAR and triceps skinfold thickness

a) BD = 1.1047 - (0.0867 × MAR) - (0.00129 × Triceps) - (0.000582 × Age)

b) BF % = (41.3 × MAR) + (0.607 × Triceps) + 0.253 × Age) - 4.7

Equation 11. MLR and triceps skinfold thickness

a) BD = 1.1040 - (0.0252 × MLR) - (0.00133 × Triceps) - (0.000546 × Age)

b) BF % = (12.0 × MLR) + 0.626 × (Triceps + 0.260 × Age) - 4.3

Equation 12. MUAC and triceps skinfold thickness

a) BD = 1.1091 - (0.00139 × MUAC) - (0.00126 × Triceps) - (0.000518 × Age)

b) BF % = (0.676 × MUAC) + (0.582 × Triceps) + (0.246 × Age) - 7.1

Units of measurements: MUAC (cm); MAR and MLR (kg/cm); age (years). r^2 and SEE values are given in **Table 3.1.3**.

Table 3.1.6. Characteristics of 146 men and 238 women from the independent validation (Wageningen) sample.

	Men (n = 146)			Women (n = 238)		
	Mean	SD	Range	Mean	SD	Range
Age (years)	45.9	17.4	18.0-82.0	36.9	17.5	20.0-83.0
Height (cm)	179.9	7.7	151.3-202.0	167.7	7.0	150.7-185.9
Weight (kg)	81.1	11.7	54.4-120.8	67.75	12.9	43.7-109.6
Body mass index (kg/m^2)	25.1	3.4	19.2-34.8	24.15	4.71	17.4-40.9
Waist circumference (cm)	93.3	10.8	70.5-115.0	82.6	11.96	62.0-113.0
Hip circumference (cm)	100.3	6.1	87.5-123.0	101.3	9.01	85.0-138.0
Waist to hip ratio	0.93	0.07	0.73-1.13	0.81	0.07	0.68-1.04
Triceps skinfold (mm)	13.6	6.0	4.0-35.5	20.0	7.7	7.0-44.0
$\Sigma_4$skinfold (mm)	57.8	25.5	18.8-152.7	69.2	30.5	22.8-155.6
Body density (kg/l)	1.034	0.02	1.008-1.079	1.023	0.02	0.984-1.062
Body fat (% body weight)	26.7	7.7	8.9-41.0	34.1	8.8	16.3-53.1

MUAC = mid-upper arm circumference; $\Sigma_4$skinfold = sum of biceps, triceps, subscapular and supra-iliac skinfolds.

Table 3.1.7. Mean body fat predicted by equations derived from determination study and by underwater weighing and their correlations, mean difference and standard errors (SE) and standard deviation of the difference in 146 men and 238 women from validation study.

	Percentage body fat			Difference (Pre-UWW)		
	Pre	UWW	r	Mean	SE	SD
Men (n = 146)						
Waist	25.71	26.65	0.839	-0.95	0.35	4.20
Triceps	28.33	26.65	0.823	1.67	0.55	6.64
BMI	24.01	26.65	0.843	-2.65	0.34	4.13
BMI + Triceps	26.87	26.65	0.850	0.22	0.46	5.55
Waist + Triceps	27.55	26.65	0.861	0.89	0.41	4.93
$Log_{10}\Sigma_4$skinfold	25.88	26.65	0.867	-0.61	0.33	3.98
$Log_{10}\Sigma_4$skinfold (D&W)	24.47	26.65	0.843	-2.01	0.35	4.14
Women (n = 238)						
Waist	35.03	34.06	0.868	0.97	0.28	4.38
Triceps	33.80	34.06	0.862	-0.26	0.33	5.12
BMI	32.19	34.06	0.879	-1.87	0.28	4.28
BMI + Triceps	32.67	34.06	0.883	-1.39	0.31	4.77
Waist + Triceps	34.76	34.06	0.883	0.70	0.29	4.54
$Log_{10}\Sigma_4$skinfold	33.88	34.06	0.882	-0.07	0.27	4.20
$Log_{10}\Sigma_4$skinfold (D&W)	32.32	34.06	0.860	-1.63	0.29	4.51

Pre = predicted body fat by anthropometric equations derived from the determination study; UWW = underwater weighing. D&W = Durnin and Womersley equations (1974).

Table 3.1.8. Slopes of the difference of body fat prediction by derived equations (adjusted for age) and body fat measured by underwater weighing plotted against body fat measured by underwater weighing in 146 men and 238 women.

	Men (n = 146)			Women (n = 238)		
	Slope	r	P	Slope	r	P
Waist	-0.787	-0.432	<0.001	-0.933	-0.464	<0.001
Triceps	0.288	0.249	0.002	-0.042	-0.024	0.710
BMI	-0.957	-0.515	<0.001	-0.651	-0.316	<0.001
BMI + Triceps	0.277	0.200	0.015	0.056	0.030	0.642
Waist + Triceps	0.191	0.123	0.134	-0.133	-0.069	0.292
$Log_{10}\Sigma_4$skinfold	-0.446	-0.232	0.005	-0.616	-0.296	<0.001
$Log_{10}\Sigma_4$skinfold (D&W)	-0.859	-0.464	<0.001	-1.212	-0.624	<0.001

D&W = Durnin and Womersley equations (1974).

Table 3.1.9. Slopes of the difference of body fat prediction by derived equations (adjusted for age) and body fat measured by underwater weighing plotted against age in 146 men and 238 women.

	Men (n = 146)			Women (n = 238)		
	Slope	r	P	Slope	r	P
Waist	-0.226	-0.055	0.512	0.303	0.076	0.242
Triceps	1.515	0.579	<0.001	1.034	0.303	<0.001
BMI	0.439	0.104	0.210	0.653	0.160	0.013
BMI + Triceps	1.344	0.430	<0.001	1.180	0.322	<0.001
Waist + Triceps	1.163	0.330	<0.001	0.779	0.202	0.002
$Log_{10}\Sigma_4$skinfold	1.214	0.276	<0.001	0.726	0.174	0.007
$Log_{10}\Sigma_4$skinfold (D&W)	-1.003	-0.237	0.004	-1.355	-0.349	<0.001

D&W = Durnin and Womersley equations (1974).

Table 3.1.10. Mean and 95% confidence limits of errors of body fat prediction by equations based on waist circumference, and skinfolds (Durnin and Womersley, 1974) from body fat measured by densitometry in different age groups of 146 men and 238 women aged 18 to 83 years.

	Men (n = 146)			Women (n = 238)		
Equation type and age groups	Mean	95% CI	n	Mean	95% CI	n
Waist circumference						
18-39	-0.5	-9.2, 8.2	48	0.6	-7.7, 8.9	138
40-59	-1.4	-9.0, 6.1	58	0.9	-8.7, 10.5	60
60-83	-0.7	-9.6, 8.2	40	0.9	-7.4, 9.3	40
Skinfold thicknesses (D&W)						
18-39	-1.6	-8.7, 5.5	47	-0.9	-8.6, 6.7	138
40-59	-1.4	-9.8, 7.0	56	-0.5	-9.5, 8.5	58
60-83	-3.4	-12.0, 5.2	40	-5.7	-14.8, 3.4	40

D&W = Durnin and Womersley equations (1974).

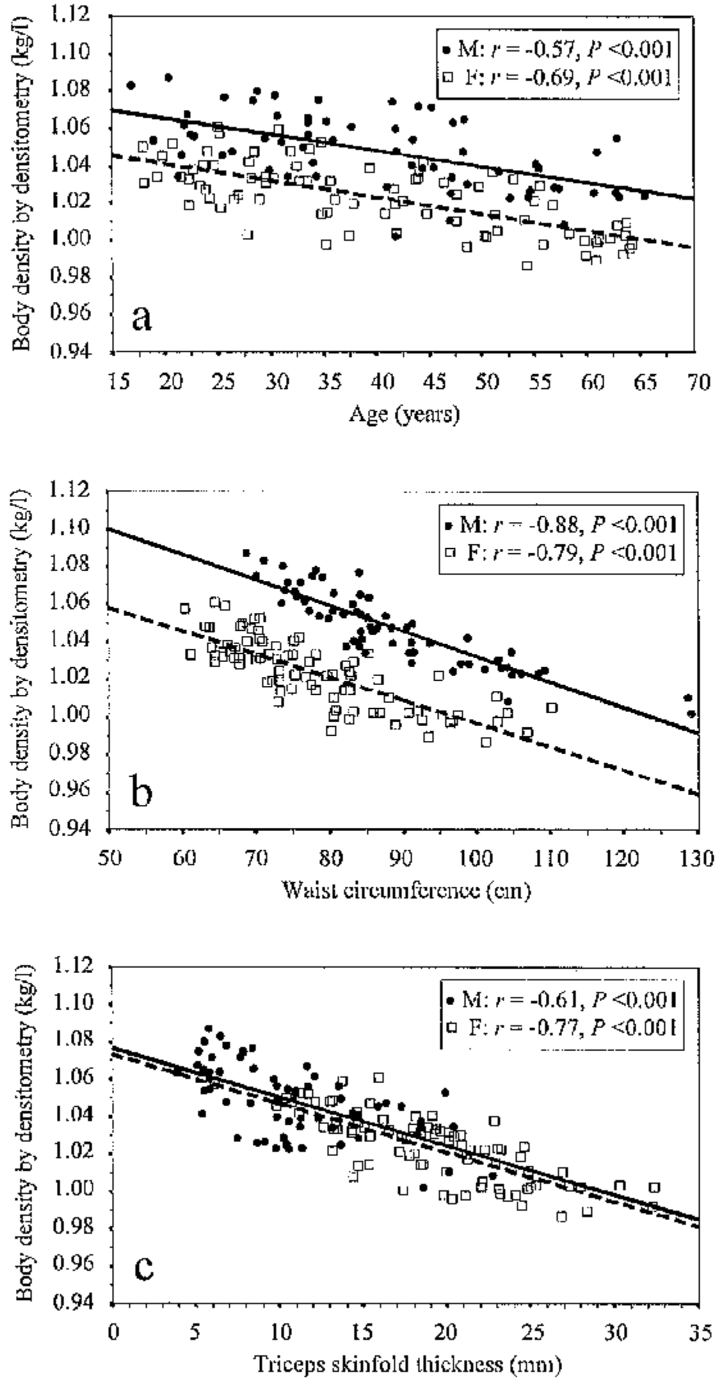


Figure 3.1.1. Relations between body density by underwater weighing and age (a), waist circumference (b), and triceps skinfold thickness (c) in 63 males (M) and 84 females (F) in the determination study.

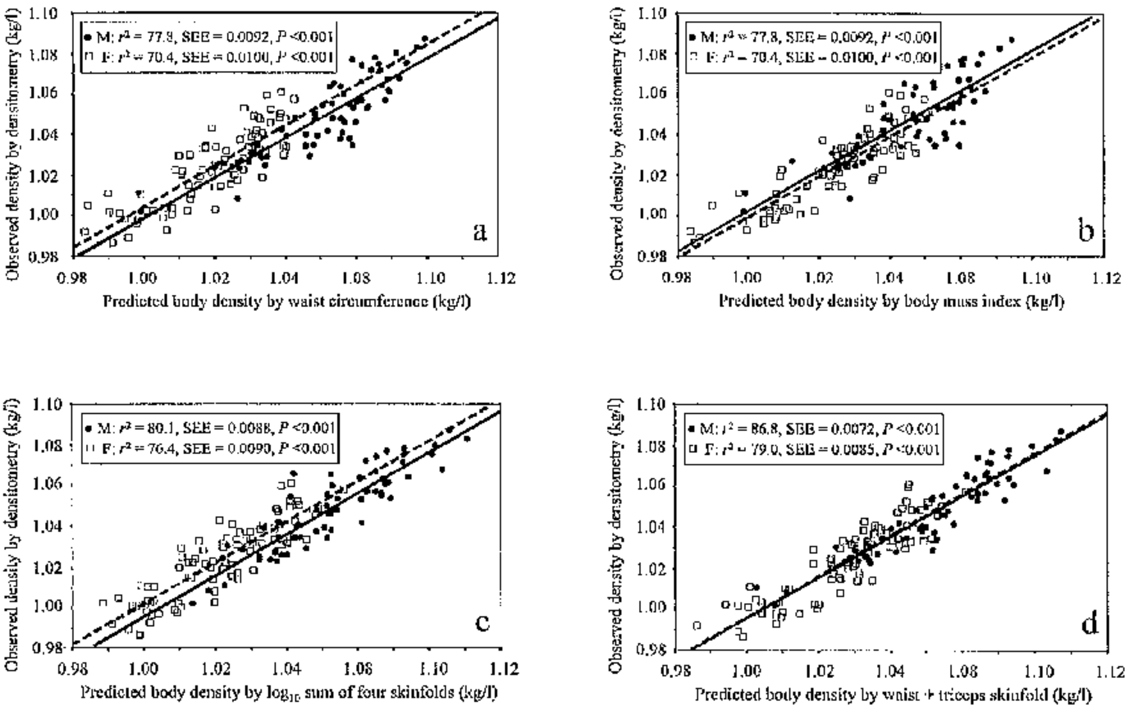


Figure 3.1.2. Relation between observed body density by underwater weighing and predicted body density by waist circumference (a), body mass index (b), log sum of four skinfold thicknesses (c), and waist + triceps skinfold thickness (d), adjusted for age, in 63 males (M) and 84 females (F) in the determination study.

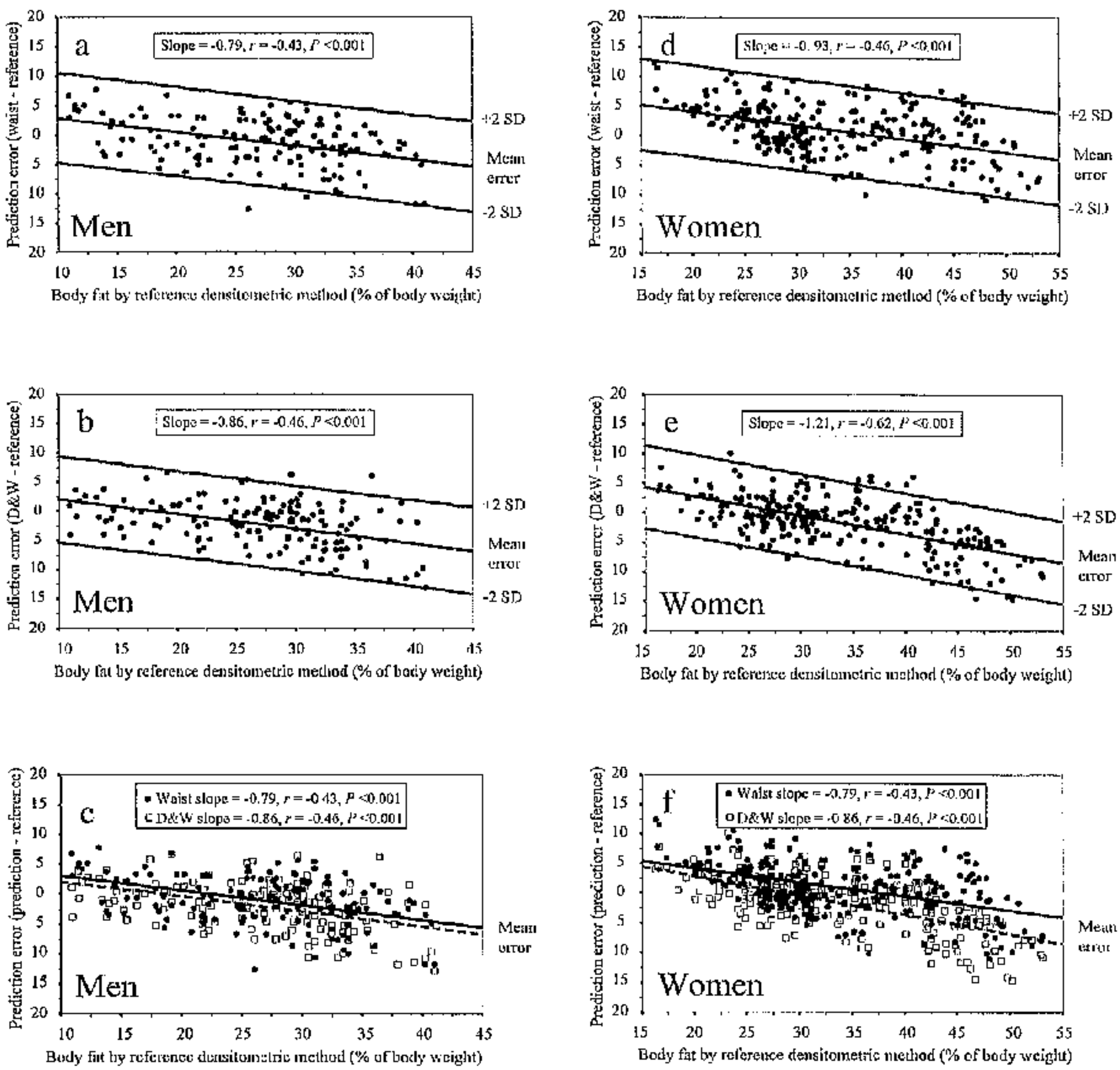


Figure 3.1.3. Plots of prediction errors of body fat (predicted minus reference densitometric method) by waist circumference in 146 men (a) and 238 women (d), and by the Durnin and Womersley (D&W) skinfold equations in men (b) and in women (e) against body fat measured by densitometry in the Wageningen validation sample. The errors of the two predictive methods are plotted against body fat by densitometry for comparison in men (c) and women (f).

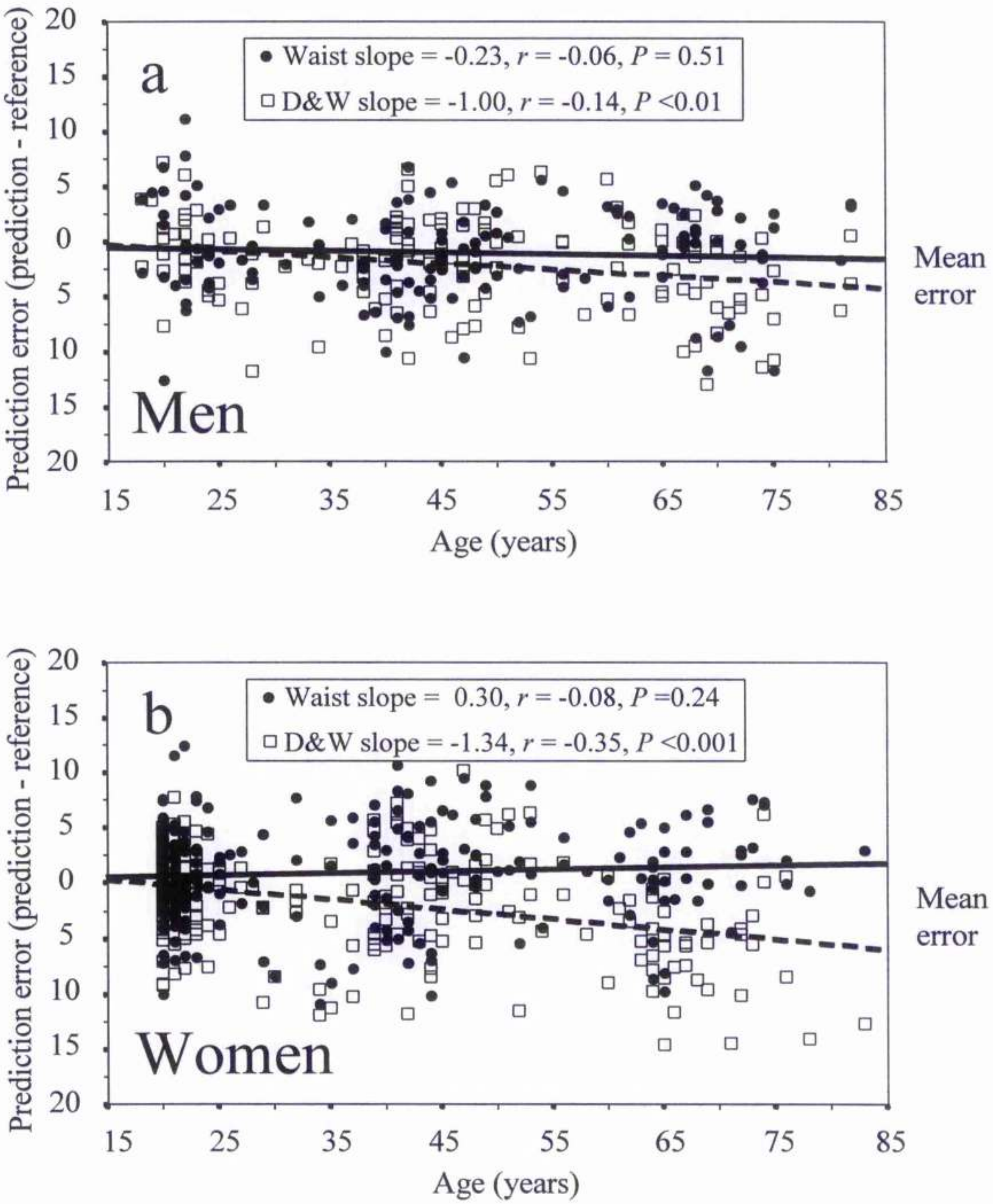


Figure 3.1.4. Plots of prediction errors of body fat (predicted minus reference densitometric method) by waist circumference and by the Durnin and Womersley (D&W) skinfold equations in 146 men (a) and in 238 women (b) against age in the Wageningen validation sample.

— 3.2 —

LIMB LENGTHS AS INDICES OF STATURE IN ADULTS, AND ALTERNATIVES TO BODY MASS INDEX FOR CHAIR- OR BED-BOUND SUBJECTS

This section has been peer reviewed and has been published as

Han TS, Lean MEJ. Lower leg length as an index of stature in adults. *International Journal of Obesity* 1996; **20**:21-27.

ABSTRACT

Objective: To derive regression equations using lower leg length (knee height) or arm span to predict height, and equations using ratios of weight/lower leg length or weight/arm span to predict body mass index and % body fat.

Subjects: Determination sample of 78 men and 82 women aged 17-70 years, and validation sample of 53 men and 121 women aged 18-82 years.

Measurements: Height, weight, lower leg length measured from the top of the patella with knee flexed at 90°, arm span, % body fat by densitometry, and age.

Results: Lower leg length gave good prediction of height (men: r^2 = 79%, SEE = 3.2 cm; women: r^2 = 73%, SEE = 3.4 cm). Weight/lower leg length ratio was highly predictive of body mass index (men: r^2 =95%, SEE = 1.1 kg/m^2, women: r^2 = 94%, SEE = 1.1 kg/m^2), and gave an estimation comparable to that of body mass index for predicting % body fat (men: r^2 = 68%, SEE = 5.0% of body weight; women: r^2 = 72%, SEE = 4.6% of body weight). Applying these equations based on lower leg length and weight/lower leg length ratio to a separate sample of men and women showed 95% of the errors of height estimate were within 6.5 cm, and of body mass index estimate were within 2 kg/m^2. The same analysis for arm span showed the errors of body composition prediction were unacceptably high.

Conclusion: Lower leg length is useful for estimating body composition when height measurement is not available.

Keywords: Anthropometry, height, knee height, ageing, stature, body mass index, body composition, body fat.

INTRODUCTION

Body mass index (BMI) and other indices which include height are used as measures of body size and composition. Measuring height is often difficult in the critically ill, the elderly, the chair/bed bound and people with musculo-skeletal injury. Standing height differs significantly from body length measured in supine subjects (Watt *et al*, 1994). Height has been predicted from demi-arm span in healthy men and women (Bassey, 1986), but Chumlea *et al* (1985) found knee height to give better prediction in the elderly.

The recent paper by Roubenoff and Wilson (1993) recommended that knee height may have an advantage over height as an index of stature in expression of body composition. The present study aimed to evaluate limb lengths as possible substitutes for height in body composition indices when height measurement is unavailable or not reliable.

METHODS

Subjects

Healthy subjects were recruited from the Glasgow area by invitations in the local press. Measurements of body stature and body composition were made in the determination sample of 78 men and 82 women aged 17-70 years, and validation sample of 53 men and 121 women aged 18-82 years available from the separate Glasgow MONICA study. This study was approved by the Glasgow Royal Infirmary's Ethical Committee.

Body composition measurements

Body weight was measured by calibrated scales (Seca, Germany) to the nearest 100 g, and height was measured to the nearest millimetre with the subjects standing, back to the stadiometer (Castlemead, Herts, UK) in bare feet. The head was adjusted so that the Frankfort plane was horizontal. Feet kept parallel with heels together. The subject was encouraged to stretch upwards by applying gentle pressure at the mastoid process. *Lower leg length* (LLL) was measured (**Figure 3.2.1**) with subjects sitting in a chair adjusted to about their knee height, and the lower legs and bare feet flexed at 90°. The lower legs, 25-30 cm apart, were adjusted to vertical position both side (**Figure 3.2.1a**) and front views (**Figure 3.2.1b**). A ruler standing on its edge was placed on top of the patellae. Lower leg length was taken to the nearest mm from the midpoint of the ruler to the floor by wooden metre rule, which was calibrated against a steel tape (Holtain, Crymych, UK) before use. This technique based on bony points aimed to reduce possible errors such as from varying mass of the quadriceps (Chumlea *et al*, 1985). *Arm span* (AS) was measured between finger tips with subjects standing against the wall, both arms fully stretched horizontally. Diurnal variations in morning and afternoon height and weight of 15 men and 25 women aged 20-46 years, and intra- and inter-observer differences in LLL and AS of 65 men and 69 women aged 17-71 years were studied.

Body density of subjects was estimated by underwater weighing, the detailed technique being described in the previous **Chapter 3.1** (Lean *et al*, 1996). Percent body fat was calculated from body density (Siri, 1961).

Statistical analyses

Determination study: Linear regression analysis was used to derive equations based on LLL or AS (independent variables) to predict morning height (dependent variable), and equations based on the ratios of weight/LLL or weight/AS to predict BMI or body fat, with the aid of *MINITAB* statistical programme (*Clecom*, Birmingham, UK). The standard error (s) of repeated measurements on the same subject was calculated as:

$$s = \sqrt{1/2n \times \sum(x_i - y_i)^2},$$

where x_i and y_i are pairs of measurements for $i = 1$ to n, and the CV was calculated as s/overall mean (Bland, 1987).

Validation study: Errors of height and BMI predictions from equations based on LLL and AS, applied to the validation sample, were calculated as the difference of the measured values from the predicted values (Gregory *et al*, 1990).

RESULTS

The mean values of anthropometric measurements of the determination sample was similar to those of the population derived MONICA validation sample for the respective sexes, except women were slightly older in the validation sample (**Table 3.2.1**), on this basis body density and percent body fat are expected to represent larger general population. The distribution of height and BMI is similar to that of the general population (Gregory *et al*, 1990). The sample was not selected to be representative of the population so height loss with ageing well known from longitudinal studies could still exist (Shephard, 1991).

Reproducibility between trained observers for LLL and AS, as CV were 0.55% and 0.72%, and within observer were 0.23% and 0.27% respectively. Study of diurnal variations (paired *t*-test) showed on average, weight increased by +0.26 (95% CI: 0.16, 0.35; P <0.05) and height decreased by -0.08 cm (-1.0, -0.6; P <0.001) in the afternoon compared to morning. These effects are compounded in estimates of BMI, so on average, BMI (weight/height^2) would increase by +0.3 kg/m^2 (1.2%) during the day.

Determination study

Equations based on LLL and AS were derived to predict height in 78 men and 82 women (**Table 3.2.2**). With the addition of age, both equations using LLL for men and women improved significantly (P <0.05). However, AS were less highly predictive of height than LLL and an age factor did not improve the prediction significantly.

Limb lengths were used instead of height, with body weight to develop indices to predict BMI (**Table 3.2.3**) and with age to predict percentage body fat (BF%) measured by densitometry (**Table 3.2.4**) in 63 men and 75 women with wide ranges of BF% and age. The ratios of weight/limb length using various index powers ranging from 0.1 to 2 for the denominator showed weight/LLL and weight/AS^2 related most strongly to BMI in both sexes. This is due to a mathematical phenomenon previously explained by

Roubenof and Wilson (1993). These ratios explained more than 91% of variance of BMI, and with age adjustment, explained ≥68% and 72% of variance of BF% in men and women respectively.

Validation study

The derived equations (**Tables 3.2.2** and **3.2.3**) from the present study were used to estimate height in a separately studied sample of 53 men and 121 women (65 women did not have arm span measurement). Mean errors and 95% confidence interval limits of estimated height from measured height of each corresponding equation are presented in **Table 3.2.5**, showing LLL predicted height to within 6.5 cm (**Equations 1a** & **1b**). There was little improvement in height prediction when equations based on LLL were adjusted for age (**Equations 2a** & **b**). Weight/LLL predicted BMI to within 2 kg/m^2 (**Equations 4a** & b). Plots of individual errors showed a systematic bias towards overestimating height in shorter subjects and underestimating height in taller subjects (**Figures 3.2.2a** & **b**). There was no systematic bias of height prediction in men of different ages (**Figure 3.2.3a**), but increasing overestimation of height in older women (**Figure 3.2.3b**). BMI prediction from LLL (**Equations 4a** & **4b**) showed no systematic bias from degree of overweight (**Figures 3.2.4a** & **b**). There were large errors (**Table 3.2.5**) in predicting height (**Equations 3a** & **3b**) and BMI (**Equations 5a** & **5b**) from AS.

DISCUSSION

Lower leg length from the present study showed good prediction of height and BMI, while prediction from AS introduced unacceptable errors. This is not surprising perhaps, since LLL is part (about 30%) of height. Height prediction from LLL in men was not affected by age (**Figure 3.2.1a**), but tended to be overestimated in older women (**Figure 3.2.3b**), which may be due to their decreasing in height as the result of ageing (Shephard, 1991), while LLL may be less affected. Therefore the estimated height could well be closer to their "true" height when the older women were at younger age. In the present study, there were no significant correlations between height and age in men from the determination sample (r = -0.183; P = 0.109) and validation sample (r = -0.182; P = 0.191) or women (r = -0.117; P = 0.294) in the determination sample, but there was a significant negative correlation between height and age in women from the validation study (r = -0.417; P <0.001), which included women who were older than the rest.

The equations in the present study were derived and validated in a Caucasian population only. Subjects were free from diseases that may have greatly affected their standing height or LLL, but some did have difficulty in holding their arm horizontal for the AS measurement. When applying LLL to estimate height, increased errors may occur in those who have deformed lower legs, or subjects of other races, whose limb/height proportion may be very different.

The derived equations based on LLL alone (**Equations 1a & 1b**) may be more practical for height estimation, since they showed comparable prediction errors to equations based on LLL with age adjustment (**Equations 2a & 2b**) when applied to the validation sample (**Table 3.2.5**).

There are various clinical situations where it is not possible to measure height or compute BMI directly. Various limb lengths have been used to predict height (**Table 3.2.6**). Bassey (1986) found a correlation coefficient of 0.75 (r^2= 56%) between height and demi-arm span in adult men and women. Higher prediction of height by knee height was observed by Chumlea *et al* (1985) in elderly men (r^2 = 67%) and women (r^2 = 56%), and r^2 increased when age was added to the equation (r^2 = 65%) in women, but not men. The age correction probably compensates for vertebral degeneration particularly in older women. In our determination study, entering age into the equations that were based on LLL significantly increased height prediction by 2% in men (t = -2.7; P < 0.01) and 4% in women (t = -3.5; P <0.001).

Lower leg length and AS were highly reproducible in our study with CV less than 1%. Chumlea *et al* (1985) found knee height measurement in the elderly was more reproducible between observers when lying recumbent (CV 0.52%) than sitting (CV 1.26%). With increasing age in women knee height was shorter by 0.06 cm per year in their study, probably because their measurement included a small, variable, amount of quadriceps muscle. Some of the prediction errors in the present study may have come from the diurnal variations of height and weight.

In a cross-sectional study, Dequeker *et al* (1969) used AS to detect differences in supine body length of women aged between 30 and 94 years, observed that AS was relatively constant throughout all age groups, but their lying body length and length/AS ratio were lower in older women. Roubenoff and Wilson (1993) showed knee height to be a better index than height for detecting changes in lean body mass with age. However they observed height was significantly lower in both older men and older women than younger subjects. Genant *et al* (1982) observed a lower vertebral bone density in those above the fifth decade or older. Since these studies were cross sectional, the effects of age or secular trend on height and limb length could not be deduced. However, some of the variance, particularly women may relate to spinal shortening with age in the present study. It is interesting that, within the women we studied, the ratio of measured height/LLL correlated negatively (r = -0.30; P <0.05) with age. If an arbitrary cut-off above age 45 years is taken in women, then there is a stronger negative correlation (r = -0.45, P <0.01) between height/LLL ratio and age. A more detailed longitudinal study of height/LLL in pre- and post-menopausal women would be of interest.

CONCLUSIONS

Lower leg length measured to the patella is a valuable index for estimating body composition when height measurement is not available, and it gives better estimates than arm span.

Table 3.2.1. Personal data of 78 men and 82 women in the determination study, and 53 men and 121 women in the validation study.

	Mean (SD)			
	Determination sample		*Validation sample*	
	Men ($n = 78$)	Women ($n = 82$)	Men ($n = 53$)	Women ($n = 121$)
Age (years)	43.9 (14.4)	43.1 (13.3)	44.1 (13.2)	46.5 (14.6)
Range	16.8-66.6	22.3-70.7	17.9-66.6	17.6-81.8
Height (cm)	175.7 (5.8)	161.8 (6.2)	175.7 (7.4)	159.8 (6.6)
Range	156.0-188.9	141.0-178.0	155.2-190.0	142.5-180.0
Weight (kg)	79.4 (15.7)	67.0 (12.1)	77.3 (11.2)	61.0 (9.7)
Range	58.8-136.5	46.1-97.3	55.8-101.1	41.0-90.0
Body mass index (kg/m^2)	25.9 (4.6)	25.8 (4.9)	25.1 (3.5)	24.0 (4.0)
Range	18.9-41.2	16.6-44.0	19.4-36.7	15.5-39.2
Lower leg length (cm)	53.6 (2.6)	49.4 (3.1)	54.2 (2.7)	48.2 (2.7)
Range	45.8-59.6	40.4-57.6	46.8-58.8	41.2-57.8
Arm span (cm)	176.5 (7.0)	160.2 (7.9)	171.4 (10.6)	157.8 (9.4)*
Range	160.0-192.5	139.8-178.0	151.8-196.2	133.5-179.1
Body fat % (% of weight)	22.3 (8.9)	33.8 (8.7)	______	______
Range	5.2-43.7	16.5-51.7	______	______
	($n = 63$)	($n = 75$)	______	______

*65 women in the validation study did not have arm span measured.

Table 3.2.2. Equations to predict height derived from 78 men and 82 women in the determination study.

From lower leg length (LLL) in cm:	
Equation 1a Men:	Height = (2.31 × LLL) + 51.1
Equation 1b Women:	Height = (1.84 × LLL) + 70.2
From lower leg length (LLL) in cm and age in years:	
Equation 2a Men:	Height = (2.30 × LLL) - (0.063 × Age) + 54.9
Equation 2b Women:	Height = (1.91 × LLL) - (0.098 × Age) + 71.3
From arm span between finger tips in cm:	
Equation 3a Men:	Height = (0.762 × Arm span) + 40.7
Equation 3b Women:	Height = (0.693 × Arm span) + 50.3

95% confidence intervals of regression coefficients of independent variables and constants, and explained variance (r^2) and standard error of the estimate to predict % body fat in equations 1, 2 and 3 to predict height.

Sex		95% CI of coefficient and constant			
		Independent variable		*Constant*	r^2 (SEE)
		LLL			
M	*Equation 1a*	2.04, 2.58		36.6, 65.7	79 (3.2)
F	*Equation 1b*	1.59, 2.09			73 (3.4)
		LLL	*Age*		
M	*Equation 2a*	2.03, 2.56	-0.110, -0.017	40.7, 69.1	81 (2.9)
F	*Equation 2b*	1.67, 2.14	-0.154, -0.043	59.7, 83.0	76 (3.2)
		AS			
M	*Equation 3a*	0.632, 0.891		17.8, 63.5	64 (4.0)
F	*Equation 3b*	0.587, 0.798		33.4, 67.2	68 (3.7)

All coefficients and constant are significant, $P < 0.05$; LLL = lower leg length; AS = armspan; M = male; F = female.

Table 3.2.3. Equations to predict BMI derived from 78 men and 82 women in the determination study.

From weight/lower leg length (Wt/LLL) in kg/cm:

Equation 4a Men: $BMI = (17.3 \times Wt/LLL) + 0.24$

Equation 4b Women: $BMI = (20.0 \times Wt/LLL) - 1.35$

From weight/arm span between finger tips (Wt/AS^2) in kg/m^2:

Equation 5a Men: $BMI = (0.936 \times Wt/AS^2) + 1.99$

Equation 5b Women: $BMI = (0.989 \times Wt/AS^2) + 0.04$

95% confidence intervals of regression coefficients of independent variables and constants, and explained variance (r^2) and standard error of the estimate to predict % body fat in equations in equations 4 and 5 to predict body mass index.

Sex		95% CI of coefficient and constant		r^2 (SEE)
		Independent variable	*Constant*	
		Wt/LLL		
M	*Equation 4a*	16.4, 18.3	-1.16, 1.64^{ns}	95 (1.1)
F	*Equation 4b*	19.2, 21.3	-2.81, 0.11^{ns}	94 (1.1)
		Wt/AS^2		
M	*Equation 5a*	0.878, 0.994	0.49, 3.49	93 (1.2)
F	*Equation 5b*	0.923, 1.055	-1.72, 1.78^{ns}	91 (1.5)

All coefficients and constant are significant, $P < 0.05$ except ns = not significant; LLL = lower leg length; AS = armspan; M = male; F = female.

Table 3.2.4. Equations to predict % body fat derived from 63 men and 75 women in the determination study.

From weight/lower leg length (Wt/LLL) in kg/cm and age in years:

Equation 6a Men: % Body fat = (24.2 × Wt/LLL) + (0.256 × Age) -22.6

Equation 6b Women: % Body fat = (21.9 × Wt/LLL) + (0.321 × Age) - 8.1

From weight/arm span between finger tips (Wt/AS^2) in kg/m^2 and age in years:

Equation 7a Men: % Body fat = (1.27 × Wt/AS^2) + (0.215 × Age) - 17.8

Equation 7b Women: % Body fat = (1.13 × Wt/AS^2) + (0.312 × Age) - 7.4

From body mass index ($weight/height^2$) in kg/m^2 and age in years:

Equation 8a Men: % Body fat = (1.33 × BMI) + (0.236 × Age) - 20.2

Equation 8b Women: % Body fat = (1.20 × BMI) + (0.287 × Age) - 7.8

95% confidence intervals of regression coefficients of independent variables and constants, and explained variance (r^2) and standard error of the estimate to predict % body fat in equations 6, 7 and 8.

Sex		95% CI of coefficient and constant			r^2 (SEE)
		Independent variable		*Constant*	
		Wt/LLL			
M	*Equation 6a*	18.4, 30.0	0.160, 0.352	-30.5, -14.7	68 (5.0)
F	*Equation 6b*	17.2, 26.6	0.207, 0.371	-15.7, -3.8	72 (4.6)
		Wt/AS^2			
M	*Equation 7a*	0.97, 1.57	0.118, 0.312	-24.6, -11.0	69 (4.9)
F	*Equation 7b*	0.88, 1.38	0.227, 0.397	-13.4, -1.4	72 (4.6)
		BMI			
M	*Equation 8a*	1.01, 1.65	0.137, 0.335	-27.6, -12.8	67 (5.0)
F	*Equation 8b*	0.97, 1.43	0.156, 0.316	-13.2, -2.4	75 (4.4)

All coefficients and constant are significant, $P < 0.05$; Wt = body weight; LLL = lower leg length; AS = armspan; BMI = body mass index; M = male; F = female.

Table 3.2.5. Mean errors and 95% confidence interval of height and BMI predictions from equations (**Tables 3.2.2 & 3.2.3**) based on lower leg length and arm span, adjusted for age where appropriate, applied to the validation sample of 53 men and 121 women.

	Dependent variable					
	Height (cm)	Mean error	95% CI	BMI (kg/m^2)	Mean error	95% CI
Men	*Equation 1a*	0.7	-5.0, 6.4	*Equation 4a*	-0.2	-2.2, 1.9
Women	*Equation 1b*	-1.0	-6.6, 4.7	*Equation 4b*	0.1	-1.8, 1.9
Men	*Equation 2a*	1.1	-4.5, 6.8	*Equation 5a*	1.7	-2.2, 5.5
Women	*Equation 2b*	-1.1	-6.3, 4.2	*Equation 5b*	1.1	-3.2, 5.4
Men	*Equation 3a*	-4.4	-15.2, 6.5			
Women	*Equation 3b*	-1.8	-10.8, 7.1			

BMI = body mass index.

Table 3.2.6. Selected studies reporting accuracy and errors of height prediction from regression equations based on limb lengths in Caucasian men and women.

Reference	Sex	*n*	Age (years)	Predictor	Height (dependent variable)	
					r^2 (%)	SEE (cm)
Han and Lean	**M**	**78**	**17-67**	**LLL**	**79**	**3.2**
Han and Lean	**F**	**82**	**22-71**	**LLL**	**72**	**3.4**
Chumlea *et al* (1985)	M	106	60-90	Knee Ht	67	3.8
Chumlea *et al* (1985)	F	130	60-90	Knee Ht	67	3.8
Han and Lean	**M**	**78**	**17-67**	**LLL+Age**	**81**	**2.9**
Han and Lean	**F**	**82**	**22-71**	**LLL+Age**	**76**	**3.2**
Chumlea *et al* (1985)	M	106	60-90	Knee Ht+Age	56	4.0
Chumlea *et al* (1985)	F	130	60-90	Knee Ht+Age	65	3.5
Han and Lean	**M**	**78**	**17-67**	**Arm span**	**64**	**4.0**
Han and Lean	**F**	**82**	**22-71**	**Arm span**	**68**	**3.7**
Bassey (1986)	M	63	35 (SD 9.7)	Demi-arm span	56	4.2
Bassey (1986)	F	62	34 (SD 9.1)	Demi-arm span	55	3.3

M = male; F = female; LLL = lower leg length; Ht = height.

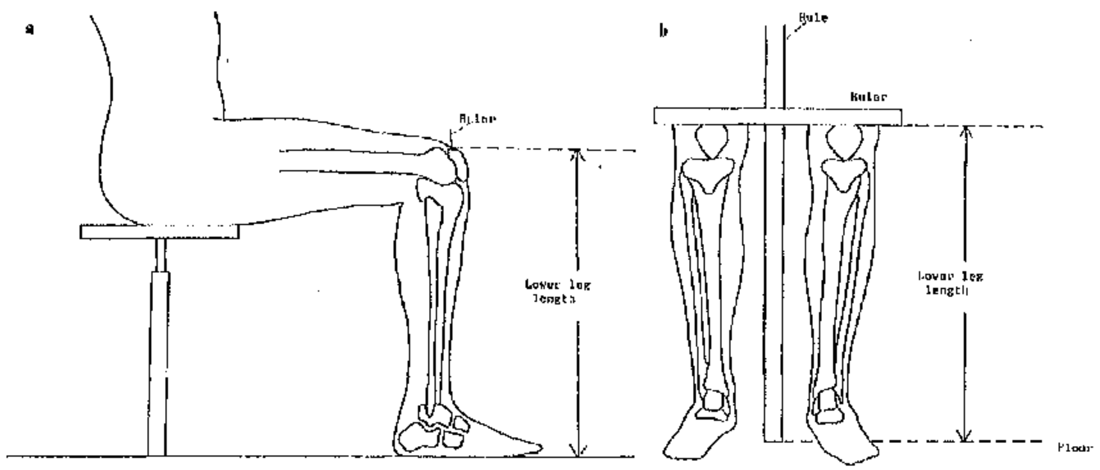


Figure 3.2.1. Methods of measuring lower leg length (see text for details).

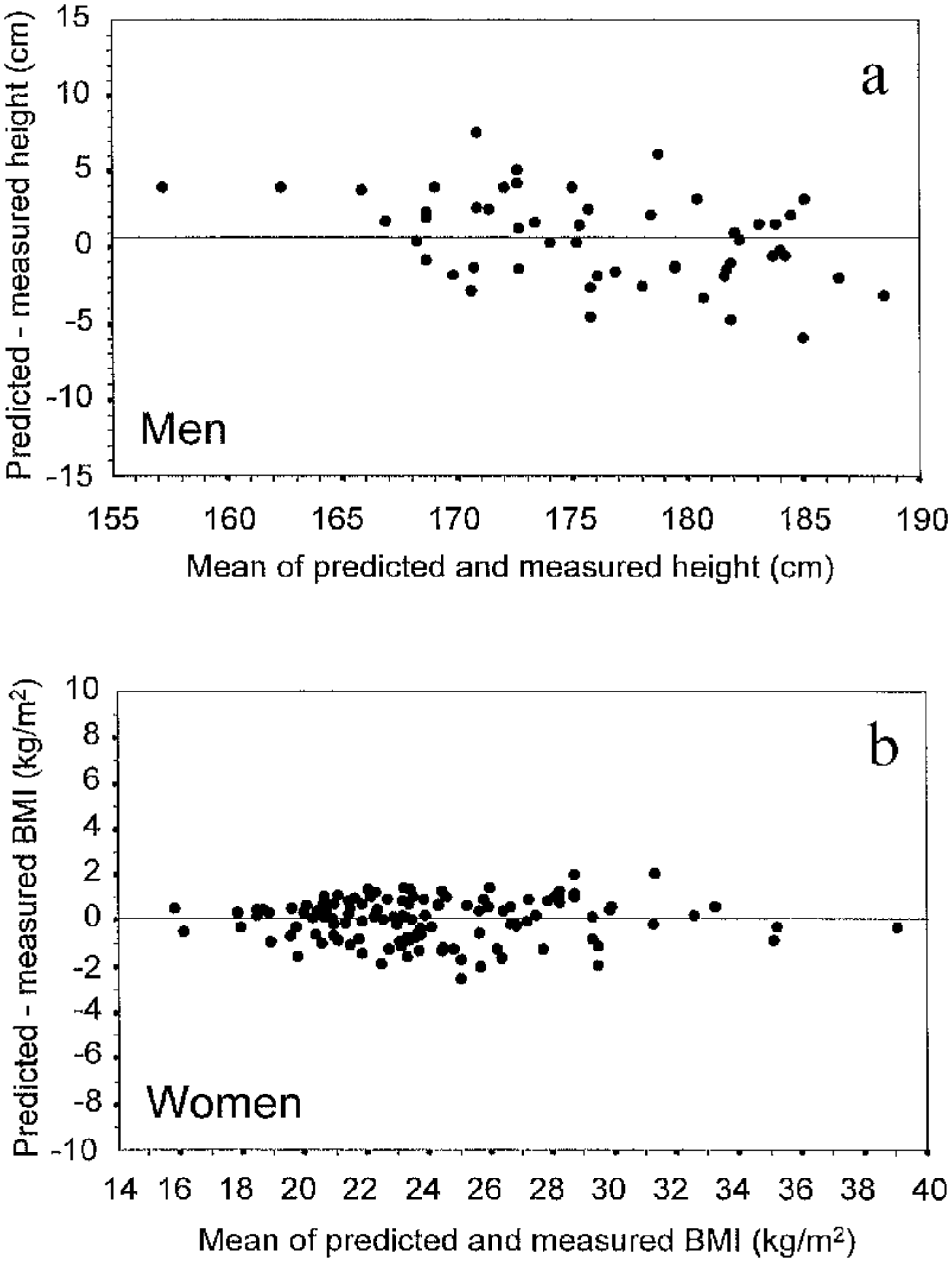
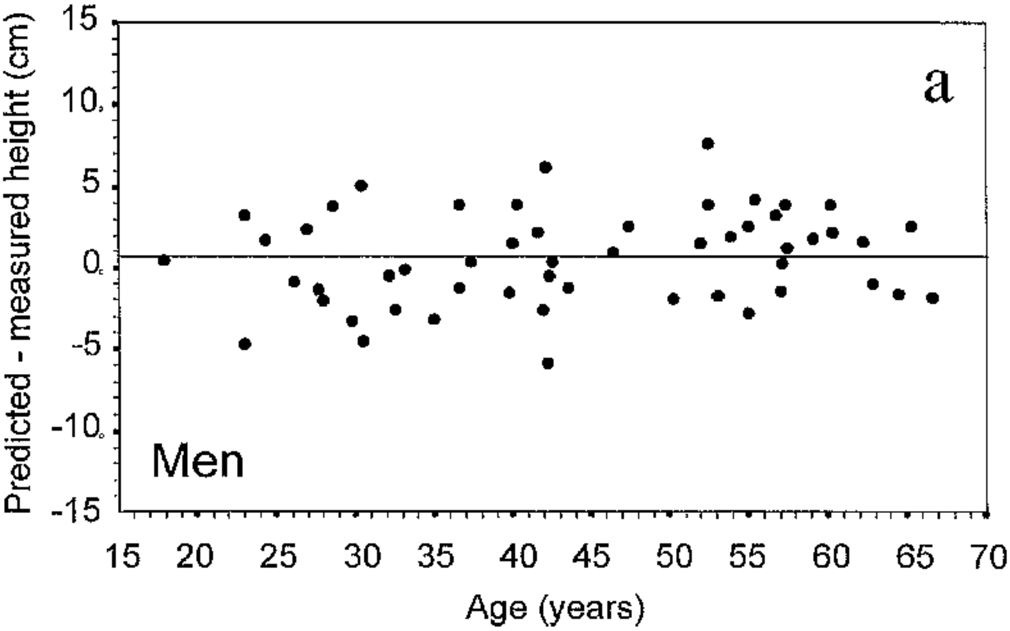


Figure 3.2.2. Plot of errors (predicted height - measured height) of height prediction by regression equations (Equation 1a and 1b) based on lower leg length against mean of predicted height and measured height in 53 men (a) and 121 women (b).



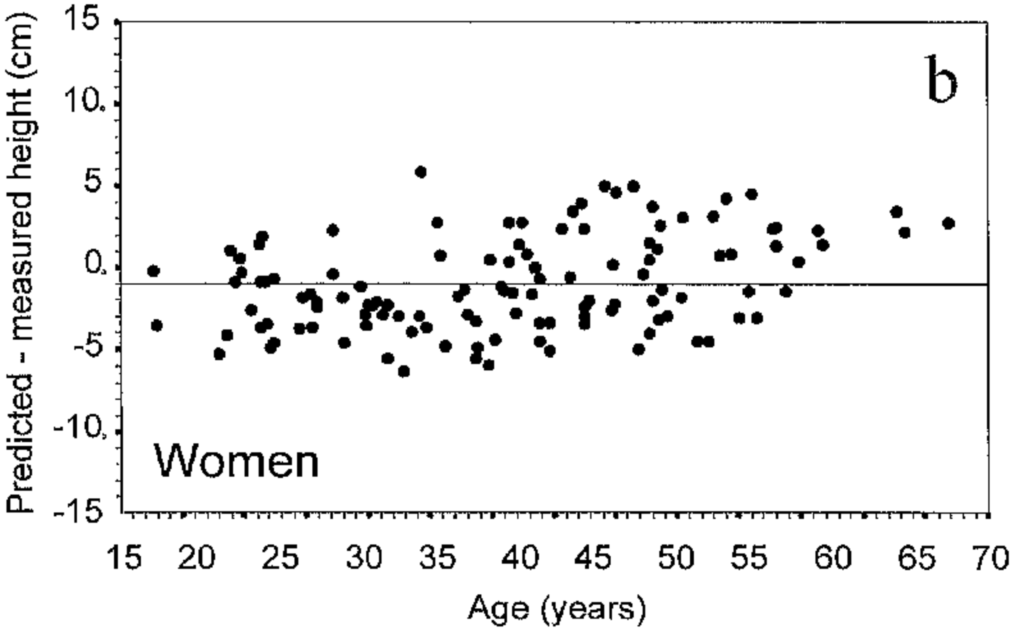
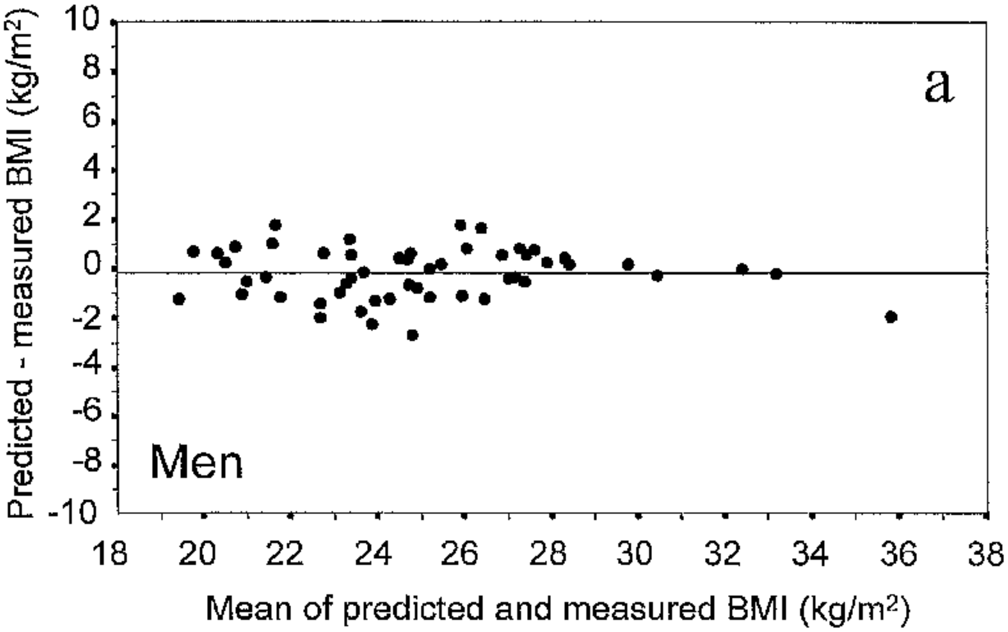


Figure 3.2.3. Plot of errors (predicted height - measured height) of height prediction by regression equations (Equation 1a and 1b) based on lower leg length against age in 53 men (a) and 121 women (b).



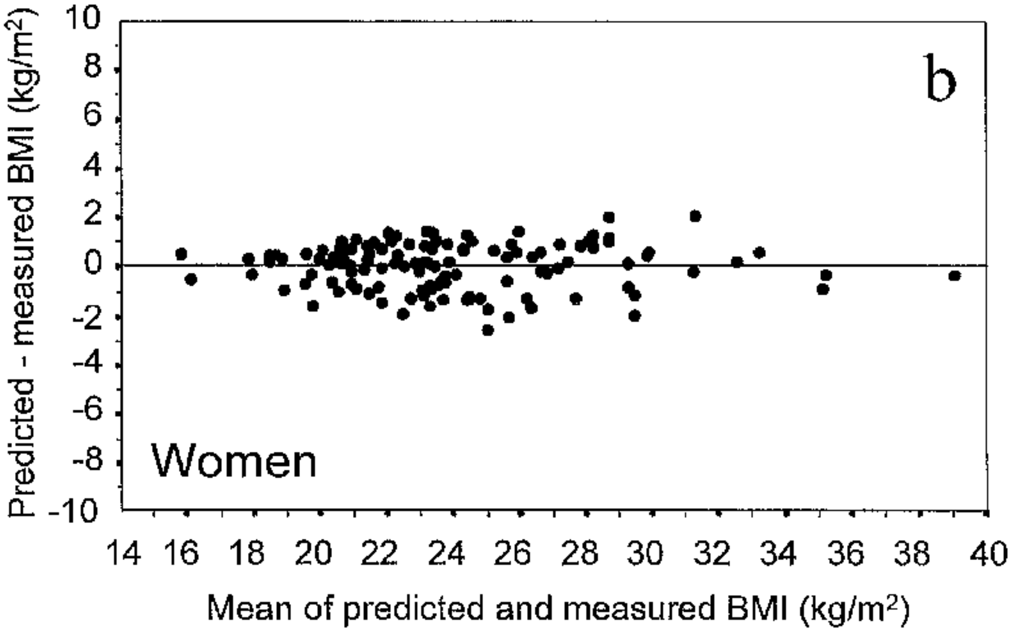


Figure 3.2.4. Plot of errors (predicted BMI - measured BMI) of BMI prediction by regression equations (Equation 4a and 4b) based on lower leg length against mean of predicted height and measured height in 53 men (a) and 121 women (b).

— 3.3 —

THE INFLUENCE OF BODY COMPARTMENTS ON BIOELECTRICAL IMPEDANCE ANALYSIS AND DENSITOMETRY

This section has been peer reviewed and has been published as

Han TS, Carter R, Currall JEP, Lean MEJ. The influence of fat free mass on prediction of body composition by bioelectrical impedance analysis and by densitometry. *European Journal of Clinical Nutrition* 1996; **50**:542-48.

ABSTRACT

Objective: To examine the effect of varying size of fat free mass (FFM) on the precision and bias of body composition prediction by bioelectrical impedance analysis (BIA) from four equations of Segal *et al* (BIA-Segal), Gray *et al* (BIA-Gray), Lukaski *et al* (BIA-Lukaski) and those from a manufacturer (BIA-EZC), by body mass index (BMI), and by skinfold methods with reference to estimation by densitometry.

Subjects: 73 men and 77 women aged 17-71 years, were measured for height, weight, FFM, bioelectrical impedance, and age.

Results: BIA-Segal gave the highest precision (men: r^2 = 83%, women: r^2 = 75%) and the least bias (men: slope = 0.88; women: slope = 0.81) of all BIA methods. There were poorer precision (r^2 ≤50%) and more bias (slope <0.70) by BIA-Lukaski and BIA-EZC in both sexes, which were comparable to the simpler BMI method. The skinfold method gave r^2 = 83% and slope = 0.84 in men, and r^2 = 61% and slope = 0.86 in women. Bland and Altman analysis showed BIA-Segal gave prediction of FFM within ±6 kg of 95% confidence interval limit of agreement of that estimated by UWW in most subjects. Other BIA methods presented unacceptably large underestimates of up to 15-17 kg in FFM.

Conclusions: The BIA-Segal provide the best predictions of the methods tested, but using BMI- or waist-specific equations may be more practical than the original BIA-Segal method, which requires the subjects' % body fat to be known in order to apply the correct equation. Other BIA methods are affected by large FFM, and not better than anthropometric methods in predicting FFM.

Keywords: fat free mass size, bioelectrical impedance, anthropometry, densitometry.

INTRODUCTION

Body composition can be indirectly estimated by a variety of methods which take advantage of different physical, physiological and biochemical characteristics of body tissues. Multi-compartment models are being developed in attempts to reduce errors resulting from assumptions inherent in conventional two compartment models of body composition prediction, but estimation of each new compartment introduces new sources of error, and traditional two-compartment models such as underwater weighing (UWW) and total body potassium counting are still widely used as reference standards. Most simple anthropometric methods are derived from UWW data, such as equations from body mass index (weight/height^2) (Deurenberg *et al*, 1991), waist circumference (**Chapter 3.1**; Lean *et al*, 1996) skinfold thicknesses (Durnin and Womersley, 1974), and from bioelectrical impedance analysis (BIA) (Segal *et al*, 1988; Gray *et al*, 1989, Lukaski *et al*, 1986).

It not clear how well these methods predict body composition in subjects of different size of fat free mass (FFM). The present study, was part of larger body composition studies which have generated and validated new equations to predict body composition from anthropometric measurements (**Chapter 3.1**; Lean *et al*, 1996). Here we have tested the influence of FFM on the precision and bias of FFM prediction and limits of agreement by BIA, calculated from three published sources, Segal *et al* (1988), Gray *et al* (1989), Lukaski *et al* (1986), and from a manufacturer (EZ Comp 1500), and the two anthropometric methods using BMI (Deurenberg *et al*, 1991) and skinfolds thicknesses (Durnin and Womersley, 1974) in 150 adult men and women aged 17 to 71 years, who had a wide range of body weight.

METHODS

Subjects

After obtaining ethical approval (Glasgow Royal Infirmary's Ethical Committee), 73 healthy Caucasian men and 77 women aged between 17-71 years were recruited by local advertisement. Body composition was assessed in the morning after an overnight fast.

All 150 subjects had UWW, BIA and anthropometric measurements made for comparison in the UWW study.

Anthropometry

Body weight in light clothes was measured to the nearest 100 g, by electronic scales (SECA, Germany), calibrated with 8×10 kg standard weights before use. Height was measured by fixed stadiometer (Castlemead, Herts, UK) to the nearest mm with the Frankfurt plane horizontal. Skinfold thicknesses were measured at biceps, triceps, subscapular and supra-iliac by calipers (Holtain, Crymych, UK) to the nearest 0.2 mm (**Chapter 3.1**; Lean *et al*, 1996; WHO, 1989). Percent body fat and thus FFM, was estimated from equations based on BMI (Deurenberg *et al*, 1991) and skinfold thicknesses (Durnin and Womersley, 1974) both of which corrected for age and sex.

Underwater weighing

Body density was taken as the mean of 4 measurements in each subject by UWW, with simultaneous 3-breath nitrogen dilution technique to correct for residual lung volume. The mean body fat was calculated from body density (Siri, 1961). Details for measuring body density are described elsewhere (**Chapter 3.1**; Lean *et al*, 1996).

Bioelectrical impedance analysis

Measurements were made with a tetrapolar BIA machine (EZ Comp 1500, Birmingham, UK) following the manufacturer's instructions. Subjects rested supine on a couch for 15-20 minutes in an enclosed thermoneutral (24-26 °C) room, without touching any metallic object. All jewellery was removed. The skin at the sensor pad sites was cleansed with alcohol to remove dead skin and oil, and dried by clean cloth. Two sensor pads were placed on the back of the right hand (on adjacent to the third metacarpal head, and the other on the arm just behind the wrist), and two on the right foot (one between the first and second metatarsals, and the other at the level of the malleoli). Arms were positioned at the sides without touching the trunk with the palm flat and prone. Legs were kept straight and apart. Subjects' weight, height, age and sex were entered into the

BIA machine for analysis with the measured bioelectrical impedance to calculate body composition from the manufacturer's equations (BIA-EZC). Measurements were repeated three times replacing the sensor pads on each occasion. The impedance (Ohms) from the BIA machine was recorded for FFM and body fat determination using the published equations of Segal *et al* (1988) (BIA-Segal). They provide specific equations for men above and below 20 % body fat and for women above and below 30 % body fat. The data were also used in the equations of Gray *et al* (1989) (BIA-Gray) who give one general equation for men and two fatness-specific equations for women (above and below 48 % body fat). Finally, the equations of Lukaski *et al* (1986) (BIA-Lukaski) which are only sex-specific, were applied.

Analysis

FFM estimations by BIA methods from four different sources (BIA-Segal, BIA-Gray, BIA-Lukaski, and BIA-EZC), by BMI, and by skinfold methods were compared with FFM measured by UWW method as reference standard. There were two issues in the comparison (Dunn, 1989). The first was estimation precision, or how well a measurement on the reference method predicted a value on the test method, estimated by the statistic R^2 which measured the percentage of the variation in the test method explained by the variation in the reference method. The limits of this statistics were 100% if the precision was perfect and 0% if there was no relationship between test and reference. The second was the bias of the test method relative to the reference method, or the degree to which there was not a one to one correspondence between the reference and the test scales. In this work we estimated the bias by the slope of a straight line regression of the test method on the reference method. If there was no bias or the bias was constant, the line would have a slope of 1. None of the methods under test showed constant bias and the non-constant bias was therefore proportional to the increase or decrease in the slope from 1.

The Bland and Altman analysis (1986) was performed to determine the magnitude of the mean error of FFM prediction of the test methods, calculated as the FFM predicted by each test method minus the mean FFM estimated by each test method and the reference UWW method. The 95% confidence intervals for the limit of bias and limit of agreement of the mean error of FFM prediction were calculated as ±2 SE and ±2 SD of the mean error, respectively.

RESULTS

Men and women had similar means and ranges of age and BMI, but on average women had a larger proportion of fat than men (**Table 3.3.1**). **Table 3.3.2** summarises the precision and bias estimates of FFM for each of the test methods relative to underwater weighing and illustrates the relative effect of the bias at high and low values of FFM. The fatness-specific equations of BIA-Segal gave the highest precision both in men (r^2 = 83%) and in women (r^2 = 75%), and the least bias (men: slope = 0.88; women: slope = 0.81) of all BIA methods. BIA-Lukaski and BIA-EZC both gave poor precision (r^2 ≤50%) and high bias (slope <0.70) for both sexes, and were thus no better than the simpler BMI method. BIA-Gray gave intermediate precision (men: r^2 = 62%; women: r^2 = 66%) and bias (men: slope = 0.78; women: slope = 0.74).

The skinfold method gave precision (r^2 = 83%) and bias (slope = 0.84) of FFM prediction similar to the BIA-Segal in men, and poorer precision (r^2 = 61%), but slightly less bias (slope = 0.86) than BIA-Segal in women (**Table 3.3.2**).

The effect of bias of FFM prediction at either large FFM (men: 80 kg, women: 55 kg) or small FFM (men: 45 kg, women: 30 kg), was assessed from regression equations using the reference UWW method to predict a value from each of the test methods. All methods overestimated FFM of small subjects and underestimated that of large subjects. The consequence of this is that the test methods compressed the range of FFM values relative to the reference (UWW). The degree of bias from size of FFM was smallest by BIA-Segal both in small subjects (men: +1.3; women: +3.1 kg FFM), and in large subjects (men: -3.0, women: -1.7 kg FFM) of all BIA methods. The effect of bias of

FFM prediction by skinfold method was similar, overestimating by +2.5 kg in small men and +3.3 kg in small women, and underestimating by -3.1 kg in large men and -0.3 kg in large women. The degree of bias from size of FFM in other methods, particularly BIA-Lukaski and BIA-EZC were relatively large, overestimating up to 5 kg in small and underestimating 10 kg of FFM in large subjects (**Table 3.3.2**).

Figures 3.3.1a-f show FFM predicted by selected test methods plotted against FFM measured by UWW to demonstrate the precision and bias of selected test methods. If there was no bias, the regression line would be identical to the line of equality. The closer the dots to the line of equality, the higher the precision of FFM prediction by test methods.

The Bland and Altman analysis (1986) was used to determine the mean prediction errors and their 95% confidence intervals of the limit of bias (±2 SE of the mean error) and limit of agreement (±2 SD of the mean error) in subgroups of subjects divided into tertiles of FFM. All methods except for the BIA-Segal and skinfold methods had significant bias in underestimating FFM of largest subjects (third tertile of FFM in men) (**Table 3.3.3; Figure 3.3.2**), and all but BIA-Gray method, had significant bias in overestimating FFM of smallest subjects (first tertile of FFM in women) (**Table 3.3.4; Figure 3.3.2**). The limits of agreement between each predicted method and reference method of UWW showed BIA-Segal equation gave prediction mostly within (95% confidence interval) 6 kg of FFM, except a slightly higher underestimation of FFM in largest men (-8.5 kg). BMI and skinfold methods gave similar limits of agreement in women. The worst prediction of FFM by other BIA equations appeared to be affected by large FFM. BIA- Gray underestimated by 15 kg FFM, and BIA-Lukaski and BIA-EZC by more than 17 kg of FFM in largest men.

The major disadvantage of the equations of Segal *et al* (1988), which was recognised by the authors, is that body fat of test subjects above or below 20% (men), 30% (women) must be known before hand so that the appropriate equations can be applied. Since % body fat estimated by UWW is highly (P <0.0001) correlated with waist circumference (men: r = 0.83; women: r = 0.78) or BMI (men: r = 0.75; women: r = 0.81), it is possible to apply their equations on the basis of waist or BMI. Regression analysis showed waist circumference cut-offs at 87 cm for men and 75 cm for women or BMI 23 kg/m^2 for men and 22 kg/m^2 for women were equivalent to body fat 20% in men and 30% in women (Han and Lean, unpublished observations).

DISCUSSION

This study tested the influence of varying size of FFM on the precision and bias of fat free mass prediction, using underwater weighing as the reference method, by four different equations of BIA and two anthropometric methods in healthy subjects. These methods are in general use for estimating body composition based on to the two compartment approach.

Although BIA methods investigated in this study used the same physical measurements, BIA-Segal and BIA-Gray equations included height and bioelectrical impedance as separate variables, whereas BIA-Lukaski uses the ratio of height/bioelectrical impedance (Z) as a single variable. The BIA-Segal equations were derived from a large pooled sample of four different laboratories containing 1069 men and 498 women, with fatness-specific equations to reduce systematic errors. The BIA-Gray equations, based on Segal *et al*'s (1988) fatness-specific equations for very obese women (>48% of body weight as fat), did not improve prediction or bias on the BIA-Segal method.

BIA methods use equations containing data identical to the BMI method (*i.e.* weight, height, age and sex) but with the extra impedance measurement, which requires a standardised protocol and the availability of the BIA machine. In terms of precision, bias, and limits of agreements of FFM prediction with reference to UWW, the simple BMI method was as good as the two methods of BIA-Lukaski and BIA-EZC.

It is well known that body composition prediction is influenced by ageing (Deurenberg *et al*, 1989; Reilly *et al*, 1994) and by body fatness (**Chapter 3.1**; Lean *et al*, 1996) and fat distribution (Han and Lean, 1994). Hydration will affect body density by UWW and BIA methods. Increasing fatness is accompanied by increased intra-abdominal fat mass (Han *et al*, 1995a), and the errors of body composition prediction from subcutaneous skinfolds will be exaggerated in those with increased intra-abdominal fat mass. The major confounding influence on the BMI method is muscularity. Variation in muscularity is most marked in men, so this may explain the particularly poor precision of FFM prediction in men by this method.

CONCLUSIONS

Of the four BIA formulae compared, body composition prediction by bioelectrical impedance analysis using different equations according to the fat content, developed by Segal *et al* (1988), had the best precision and least bias, and closest agreement of FFM prediction with reference to the UWW method. The other methods were affected by varying size of FFM and no better than the simple BMI method (Deurenberg *et al*, 1991). Although the fatness-specific BIA-Segal equation (Segal *et al*, 1988) was comparable to the skinfold method (Durnin and Womersley, 1974), it is not practical as subjects' percentage body fat must be known before hand for applying appropriate equations. Using waist- or BMI-specific equations may be more practical.

Table 3.3.1. Characteristics of subjects.

	Men (n = 73)			Women (n = 77)		
	Mean	SD	Range	Mean	SD	Range
Age (years)	43.7	14.3	16.8-66.6	42.9	13.4	22.3-70.7
Weight (kg)	79.0	14.5	58.8-122.1	66.7	12.4	46.1-97.3
Height (m)	1.75	0.06	1.61-1.88	1.62	0.06	143-1.78
Body mass index (kg/m^2)	25.7	4.4	18.9-41.2	25.6	4.8	18.3-37.5
Fat free mass (kg)*	59.6	7.6	46.3-82.8	42.6	4.9	31.6-55.7
Body fat (% of body weight)*	23.6	8.5	5.2-43.7	34.8	8.9	16.5-51.7

*Estimated by underwater weighing (% body weight).

Table 3.3.2. The precision of estimation (as measured by R^2) and bias (as measured by regression slope) of fat free mass estimated by different test methods: bioelectrical impedance, body mass index and skinfold, calibrated against fat free mass estimated by underwater weighing as a reference method. Estimates of fat free mass on the test methods for fat free mass by underwater weighing of 45 and 80 kg for men and 30 and 55 kg for women are given to illustrate the effect of bias at both ends of the range of subjects in the study.

	Men (n = 73)				Women (n = 77)			
Method	R^2 (%)	Slope (SE)	45 kg (SE)	80 kg (SE)	R^2 (%)	Slope (SE)	30 kg (SE)	55 kg (SE)
BIA-Segal	83	0.88 (0.046)	46.3 (0.75)	77.0 (1.00)	75	0.81 (0.053)	33.1 (0.72)	53.3 (0.71)
BIA-Gray	62	0.78 (0.071)	45.8 (1.18)	72.9 (1.57)	66	0.74 (0.062)	33.2 (0.83)	51.8 (0.82)
BIA-Lukaski	48	0.68 (0.084)	46.7 (1.38)	70.5 (1.84)	50	0.69 (0.079)	34.7 (1.07)	52.0 (1.05)
BIA-EZC	46	0.69 (0.087)	46.2 (1.43)	70.4 (1.90)	47	0.68 (0.082)	35.0 (1.10)	51.9 (1.08)
BMI	70	0.65 (0.050)	49.2 (0.82)	71.9 (1.09)	58	0.68 (0.066)	33.9 (0.89)	50.8 (0.87)
Skinfold	83	0.84 (0.045)	47.5 (0.74)	76.9 (0.99)	61	0.86 (0.079)	33.3 (1.07)	54.7 (1.05)

BIA = bioelectrical analysis; BMI = body mass index.

Table 3.2.3. Mean errors of FFM prediction and limits of bias and limits of agreement by different methods for subjects in each tertile of mean FFM in men.

		95% confidence interval limits	
	Mean error†	Bias‡	Agreement§
First tertile of FFM (n = 24)¶			
BIA-Segal	-0.3	-1.4, 0.7	-5.5, 4.8
BIA-Gray	-2.0	-4.0, 0.0	-11.8, 7.9
BIA-Lukaski	-3.0*	-4.8, -1.2	-11.8, 5.8
BIA-EZC	-3.8*	-5.3, -2.3	-11.3, 3.7
BMI	-0.3	-1.7, 1.1	-7.2, 6.6
Skinfold	0.8	-0.2, 1.8	-4.1, 5.7
Second tertile of FFM (n = 25)¶			
BIA-Segal	-0.3	-1.4, 0.9	-5.9, 5.4
BIA-Gray	-2.4*	-4.0, -0.8	-10.3, 5.6
BIA-Lukaski	-2.4*	-4.9, -0.0	-14.7, 9.8
BIA-EZC	-2.8*	-5.6, -0.0	-16.9, 11.2
BMI	0.6	-1.0, 2.1	-6.9, 8.0
Skinfold	0.0	-1.3, 1.4	-6.7, 6.8
Third tertile of FFM (n = 24)¶			
BIA-Segal	-0.9	-2.5, 0.7	-8.5, 6.7
BIA-Gray	-3.1*	-5.5, -0.7	-14.7, 8.5
BIA-Lukaski	-3.5*	-6.4, -0.6	-17.7, 10.8
BIA-EZC	-3.3*	-6.2, -0.5	-17.2, 10.6
BMI	-3.1*	-5.0, -1.3	-12.0, 5.8
Skinfold	-0.3	-1.8, 1.1	-7.3, 6.6

FFM = fat free mass; BMI = body mass index; BIA = bioelectrical impedance analysis. Significance level: *P <0.05; †mean error = FFM by each test method minus FFM by UWW; ‡limit of bias = ±2 SE of the mean errors; §limit of agreement = ±2 SD of the mean errors; ¶mean FFM = (FFM by each test method + FFM by UWW)/2.

Table 3.2.4. Mean errors of FFM prediction and limits of bias and limits of agreement by different methods for subjects in each tertile of mean FFM in women.

		95% confidence interval limits	
	Mean error†	Bias‡	Agreement§
First tertile of FFM (*n* = 26)¶			
BIA-Segal	1.1*	0.4, 1.8	-2.4, 4.6
BIA-Gray	0.7	-0.2, 1.5	-3.7, 5.0
BIA-Lukaski	1.0*	0.1, 2.0	-3.7, 5.7
BIA-EZC	1.0*	0.0, 2.3	-4.0, 6.0
BMI	0.8*	0.0, 1.6	-3.3, 4.9
Skinfold	1.4*	0.3, 2.5	-4.2, 7.0
Second tertile of FFM (*n* = 25)¶			
BIA-Segal	0.9	-0.2, 2.0	-4.6, 6.4
BIA-Gray	0.1	-1.2, 1.4	-6.3, 6.6
BIA-Lukaski	1.1	-0.4, 2.1	-6.5, 8.6
BIA-EZC	1.3	-0.3, 2.9	-6.8, 9.4
BMI	-0.4	-1.9, 1.1	-7.9, 7.2
Skinfold	1.1	-0.2, 2.5	-5.7, 7.9
Third tertile of FFM (*n* = 26)¶			
BIA-Segal	0.1	1.0, 1.1	-5.2, 5.3
BIA-Gray	-0.8	-2.0, 0.4	-6.9, 5.3
BIA-Lukaski	0.4	-1.5, 2.2	-8.8, 9.5
BIA-EZC	0.4	-1.4, 2.2	-8.7, 9.5
BMI	-1.0	-2.3, 0.3	-6.7, 5.7
Skinfold	1.9*	0.3, 3.5	-6.1, 9.9

FFM = fat free mass; BMI = body mass index; BIA = bioelectrical impedance analysis. Significance level: *P <0.05; †mean error = FFM by each test method minus FFM by UWW; ‡limit of bias = ±2 SE of the mean errors; §limit of agreement = ±2 SD of the mean errors; ¶mean FFM = (FFM by each test method + FFM by UWW)/2.

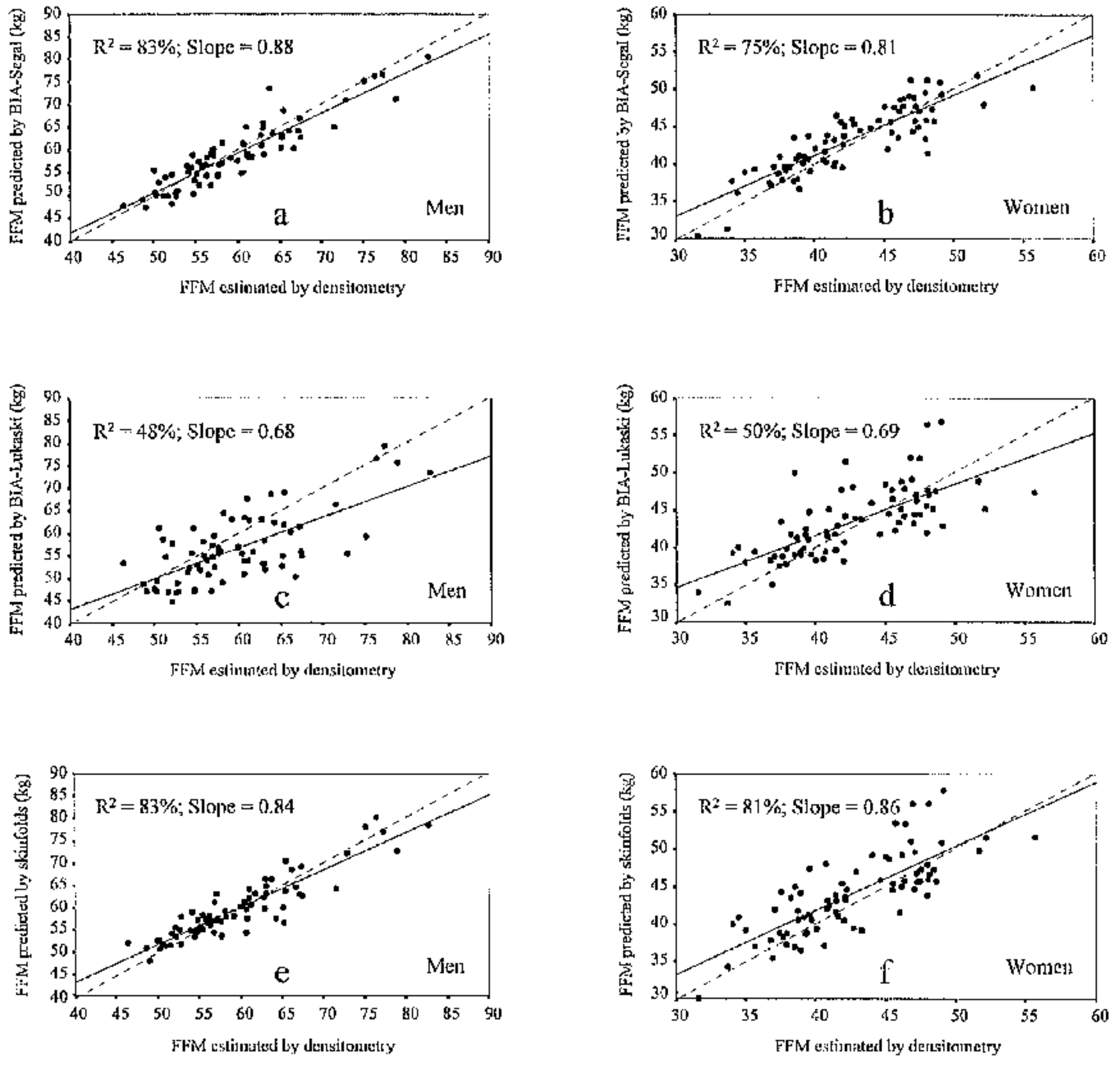


Figure 3.3.1. Plots of fat free mass (FFM) predicted by bioelectrical impedance analysis (BIA) using equations from Segal *et al* (a and b), Lukaski *et al* (c and), skinfold method (e and f) against FFM estimated by densitometry, showing the precision (R^2) and bias (slope) of FFM prediction in 73 men and 77 women. Solid line indicates line of regression, and dashed line indicates line of equality.

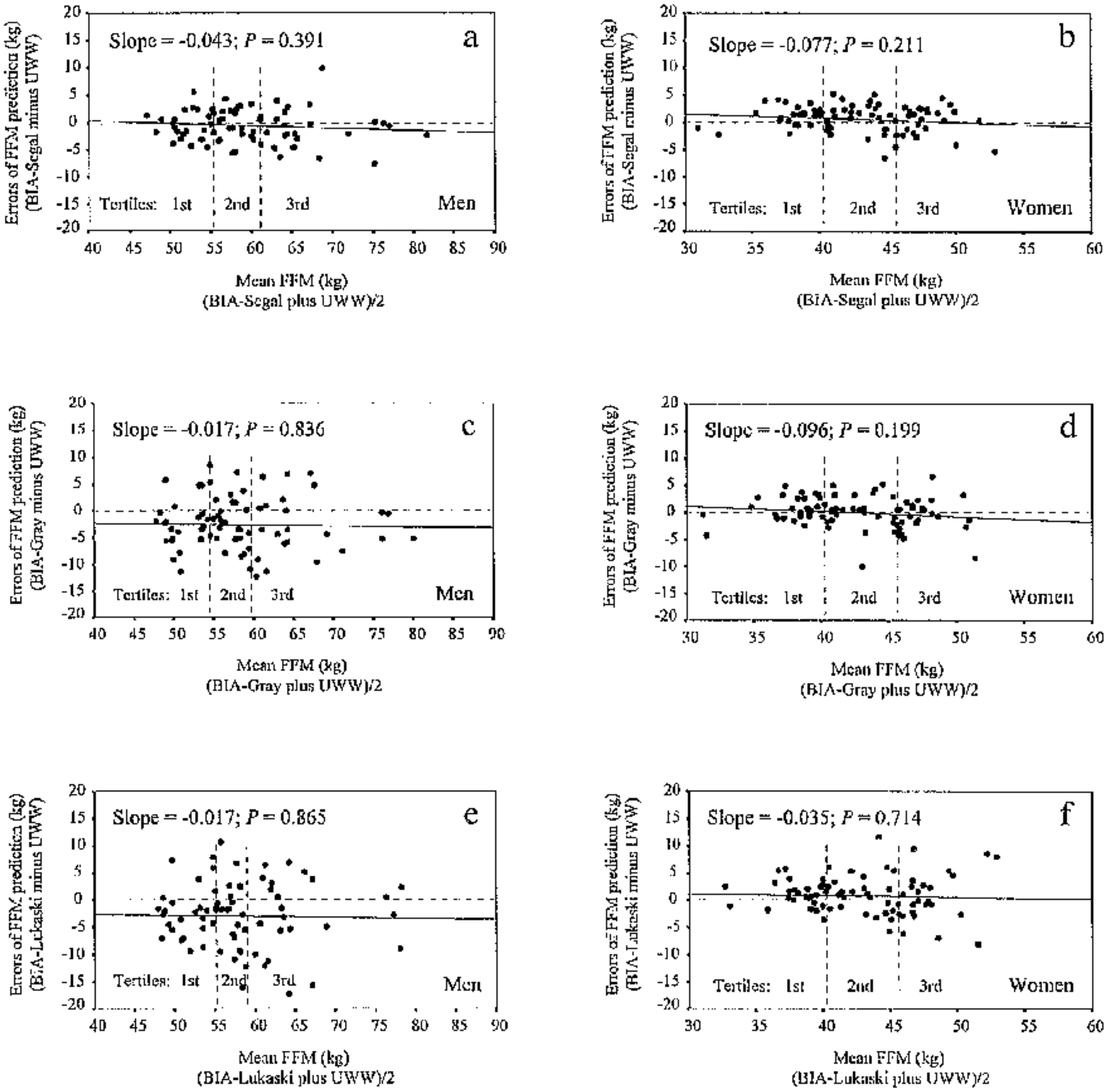


Figure 3.3.2. Plots of errors of FFM prediction (FFM predicted by test method minus FFM estimated by reference UWW method) against mean FFM (test method and the reference UWW method), for the test methods using equations from: a and b (Segal *et al*, 1988); c and d (Gray *et al*, 1989); e and f (Lukaski *et al*, 1986). Vertical dashed lines separate tertiles of mean FFM.

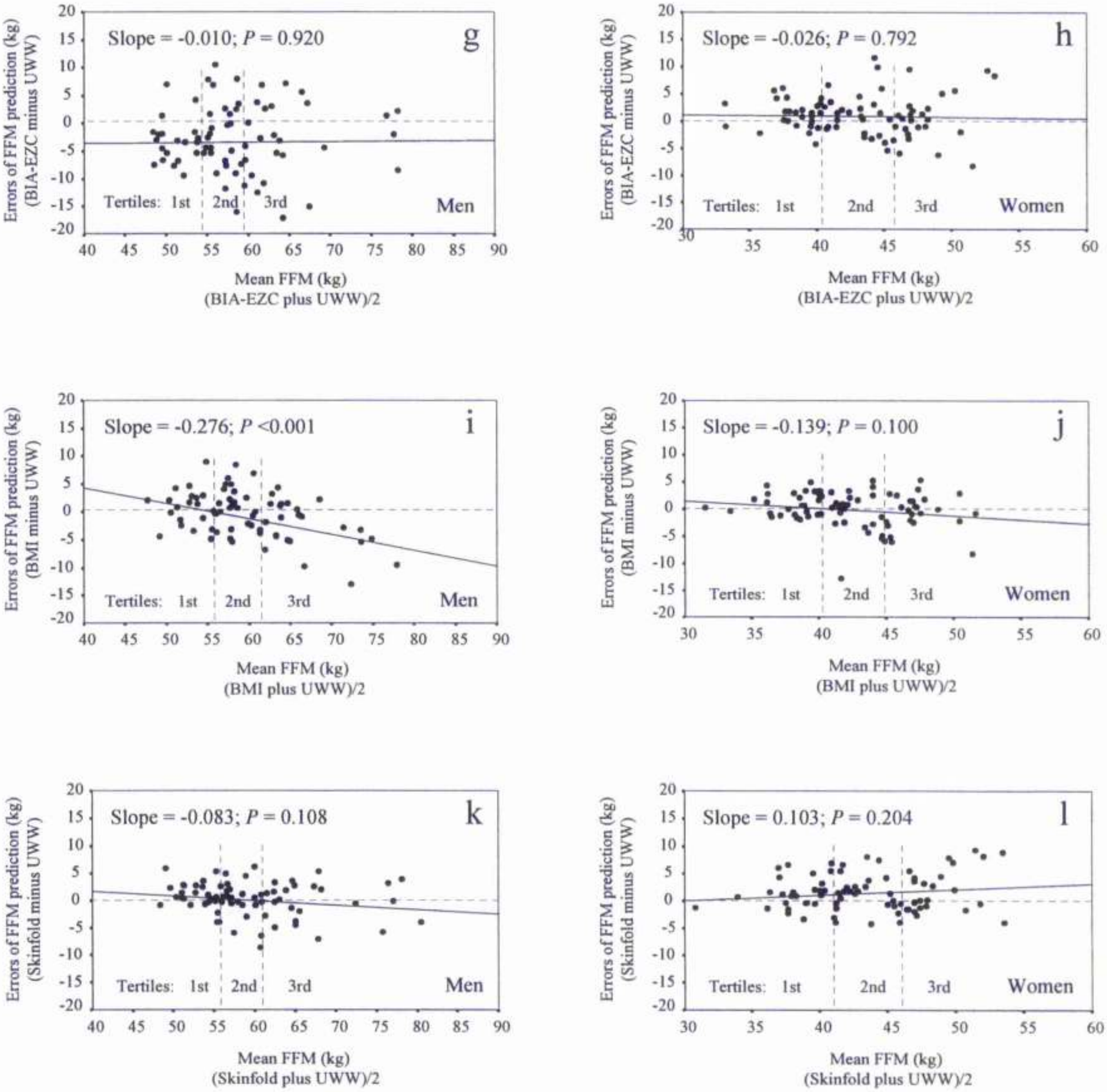


Figure 3.3.2. - continued. Plots of errors of FFM prediction (FFM predicted by test method minus FFM estimated by reference UWW method) against mean FFM (test method and the reference UWW method), for the test methods using equations from: g and h (from a manufacturer); i and j, from BMI (Deurenberg *et al*, 1991); k and l, from skinfolds (Durnin and Womersley, 1974). Vertical dashed lines separate tertiles of mean FFM.

CHAPTER FOUR

DEVELOPMENT OF SIMPLE ANTHROPOMETRIC INDICES FOR HEALTH PROMOTION

CONTENTS OF CHAPTER FOUR — PAGES

WAIST CIRCUMFERENCE AS A MEASURE FOR INDICATING NEED FOR WEIGHT MANAGEMENT: DEVELOPMENT OF CUT-OFFS FOR HEALTH PROMOTION

This section has been peer reviewed and has been published as

Lean MEJ, **Han TS**, Morrison CE. Waist circumference as a measure for indicating need for weight management. *British Medical Journal* 1996; **311:**158-61.

Collaboration with WHO MONICA project.

ABSTRACT

Objective: To test the hypothesis that a single measurement, waist circumference, might be used to identify people at health risk both from being overweight and from having a central fat distribution.

Design: A community derived random sample of men and women and a second, validation sample.

Setting: North Glasgow.

Subjects: 904 men and 1014 women (first sample); 86 men and 202 women validation sample.

Main outcome measures: Waist circumference, body mass index, waist:hip ratio.

Results: Waist circumference ≥94 cm (37") for men or ≥80 cm (31.5") for women identified individuals with high body mass index ≥25 kg/m^2 and those with lower body mass index but high waist:hip ratio (≥0.95 for men, ≥0.80 women) with a sensitivity of >96%, and specificity >97.5%. Waist circumference ≥102 cm (40") for men or ≥88 cm (34.5") for women identified subjects with body mass index ≥30 kg/m^2 and those with lower body mass index but high waist:hip ratio with a sensitivity of >96% and specificity >98%, with only about 2% of the sample being misclassified.

Conclusions: Waist circumference could be used in health promotion programmes to identify individuals who should seek and be offered weight management. Men with waist circumference ≥94 cm for men and women with waist circumference ≥80 cm should gain no further weight; men with waist circumference ≥102 cm and women with waist circumference ≥88 cm should reduce their weight.

Keywords: body mass index, waist circumference, waist:hip ratio, weight loss, obesity, risk factors.

INTRODUCTION

About half of all British adults have a body mass index (weight (kg)/height (m^2)) of >25 kg/m^2, almost 15% >30 kg/m^2 and these proportions are rising (Gregory *et al*, 1990; Bennett *et al*, 1995). Given the lack of success of the management of obesity and increasing associated health costs (Secretary of State for Health, 1991; Scottish Office, 1992), greater emphasis on prevention is needed, particularly in young people, who often have little contact with health services. While many health professionals are now familiar with the acceptable range for body mass index (20-25 kg/m^2) (Bennett *et al*, 1995; Cardiovascular Review Group Committee on Medical Aspects of Food, 1994) most members of the public cannot readily calculate their index to establish their own risk or need for weight management. Charts developed by the Health Education Authority (1991) are helpful, but are still not understood by many. Height must be measured accurately as small errors in the denominator are exaggerated by squaring.

The major metabolic cardiovascular risk factors (high blood pressure, plasma lipids, insulin resistance) all aggregate independently with both body mass index and waist:hip ratio (Björntorp, 1987; Seidell *et al*, 1989b) and improve with weight loss (Casimirri *et al*, 1989; den Besten *et al*, 1988; Dennis *et al*, 1993; Kanaley *et al*, 1993; van Gaal, 1990). The circumference of the waist relates closely to body mass index and is also the dominant measurement in the waist:hip ratio, which reflects the proportion of body fat located intra-abdominally, as opposed to subcutaneously (Björntorp, 1987), and waist circumference is the best indicator of changes in intra-abdominal fat during weight loss (van der Kooy *et al*, 1993).

We evaluated waist circumference as a simple predictor of health risk from being overweight and through the central distribution of fat to indicate levels at which individuals should take action.

METHODS

Subjects

Determination study

We randomly recruited of 904 men and 1014 women, aged 25 to 74 years, from the general population of north Glasgow between January and August 1992, excluding only those who were chair bound.

Validation study

We recruited separately 86 men and 202 women by advertising locally to test the proposed Action Level (levels at which individuals may at risk from being overweight) derived in the determination study.

Anthropometry

All measurements were made by trained observers with standard techniques (World Health Organisation, 1989): weight by digital scales (Seca, Germany) to within 100g, without heavy clothing; height barefoot by portable stadiometer (Holtain, Crymych, United Kingdom) to 0.5 cm; circumferences to within 1 mm with plastic tapes calibrated weekly, with waist mid-way between the lowest rib and iliac crest with the subject standing at the end of gentle expiration, and hips at the greater trochanters. We used the same methods determine and validate studies by different researchers.

Methods of analysis

Combination with indices in the range height$^{0.1}$ to height^2 did not improve the correlations of waist circumference alone with body mass index ($r = 0.89$; $P < 0.001$ for both sexes). According to the criteria of Khosla and Lowe (1967), height was therefore not used with waist circumference for further analyses.

We determined by cross tabulation between variables (Norušis, 1993) two Action Level for waist circumference for weight management to identify most subjects with body mass index ≥ 25 kg/m^2 (Action Level 1) and ≥ 30 kg/m^2 (Action Level 2), while including a minimum of subjects who had lower body mass index and low waist:hip ratio to maximise sensitivity and specificity (Hanson, 1988). High body mass index was defined at two levels as ≥25 or ≥30 kg/m^2 for both men and women (Health Education Authority, 1991). On the basis of consensus from previous studies (Casimirri *et al*, 1989; Den Besten *et al*, 1988; Dennis *et al*, 1993; Kanaley *et al*, 1993; van Gaal, 1990), high waist:hip ratio was defined as ≥0.95 for men and ≥0.80 for women and low waist:hip ratio as below these cut-offs.

RESULTS

Determination Study

The mean age (range 25 to 74 years), body mass index, and hip circumference were similar for men and for women (**Table 4.1.1**). However, men were heavier and taller and had a larger waist circumference and waist:hip ratio than women. In both sexes, waist:hip ratio correlated positively with body mass index (men, r = 0.63; women: r = 0.39; both P <0.001) (**Table 4.1.2**). Waist circumference correlated weakly with height in men (r = 0.19; P <0.05), but not women (r = 0.06, P = 0.06). On average, men with waist circumference above 'Action Level 1' were 2 cm taller than those below, accounting for 0.7 cm difference in waist circumference, but Action Level for waist circumference determined for four different height categories (not shown) did not differ.

Figure 4.1.1 shows distributions of the waist circumference related to body mass index divided by the proposed Action Level. **Table 4.1.3** show the numbers in different categories of waist circumference, body mass index, waist:hip ratio. 'True positive' subjects were those with high body mass index and those with lower body mass index but high waist:hip ratio; 'true negative' subjects were those with low body mass index and those with high body mass index but low waist:hip ratio. 'False positive' subjects were those with waist circumference above the Action Level but with low body mass index and waist:hip ratio; false negative' subjects were those with waist circumference below the Action Level but with high body mss index and waist:hip ratio. These numbers were used to determine the sensitivity and specificity for waist circumference as an indicator of need for weight management (**Table 4.1.4**).

False negative subjects, who would be missed by health education, targeted using waist circumference, would represent under 1.5% of the population. 'False positive' individuals (1.7% of the total population) would be included inappropriately by health promotion directed at those with high waist circumference. Amongst false positives at Action Level, men had body mass indices 23.2-24.8 kg/m^2 and waist:hip ratios 0.91-0.95, and women had body mass indices 23.0-24.9 kg/m^2 and waist:hip ratios 0.77-0.80. Amongst false positives at Action Level 2, men had body mass indices 26.9-29.7 kg/m^2 and waist:hip ratios 0.88-0.94, and women had body mass indices 28.7-29.6 kg/m^2 and waist:hip ratios 0.79-0.80. Misclassified individuals were thus close to the levels at which weight loss would be recommended, and hazards of health promotion based on waist circumference Action Levels would be minimal.

Validation study

The validation sample was younger than the determination sample, but had similar ranges of anthropometric measurements(**Table 4.1.1**). The Action Levels of waist circumference showed similarly high sensitivity (>94%) and specificity (>97%) for identifying high risk individuals in need of weight management (**Tables 4.1.3 & 4.1.4**). There was no significant relationship between waist circumference and height in either men (r = 0.07; P = 0.54) or women (r = -0.13; P = 0.07).

DISCUSSION

The influences of body mass index and waist:hip ratio on metabolic and cardiovascular disease are multiplicative (Lapidus *et al*, 1984; Larsson *et al*, 1984; Ohlson *et al*, 1985), so weight loss should be urged for all those with high body mass index, and can also be justified for those with lower body mass index but high waist:hip ratio. Consensus emerging from prospective studies suggests cut-offs of waist:hip ratio 0.95 in men and 0.80 in women as figures above which health risk increases importantly. Metabolic risk factors, particularly serum triglycerides and high density lipoprotein cholesterol improve most from weight loss in men (Sönnichsen *et al*, 1992; Houmard *et al*, 1994; Wing *et al*, 1992) with waist:hip ratio ≥0.95 and women (den Besten *et al*, 1988; Dennis *et al*, 1993; Kanaley *et al*, 1993) with waist:hip ratio ≥0.80 (**Table 4.1.5**). In the present study, 48% of the women and a 33% of the men had waist:hip ratios above these figures (**Table 4.1.2**); well over half had body mass indices above 25 kg/m^2. The interaction between body mass index and waist:hip ratio offers through waist circumference an opportunity to target individuals at highest risk in order to maximise the benefits of interventions (Davey Smith *et al*, 1993; Yudkin, 1993).

Many analyses have found strong positive correlations between waist circumference and body mass index. This relationship alone allows only limited prediction of body mass index: in the present study, waist circumference would misclassify about 4% men and 7% women in attempting to identify those with body mass index ≥25 kg/m^2, or 10% men and 11% women at body mass index ≥30 kg/m^2. Health promotion targeted by waist circumference at those with body mass index ≥25 kg/m^2 would miss about 21% of the total at risk population (≥25 kg/m^2), and about 10% of those identified would be targeted inappropriately. However, most of those with high waist circumference but body mass index below these conventional cut-offs have high waist:hip ratio, which still justifies weight management. Most of those with higher body mass index but waist circumference below the Action Level have low waist:hip ratio, which would indicate a lower health risk, and less benefit from slimming. The Action Level for waist circumference derived here, based on both body mass index and waist:hip ratio, are robust in that they misclassified only 1.5% of the overweight men and women.

The simplicity of measurement and its relation to both body weight and fat distribution are major advantages for waist circumference over body mass index and waist:hip ratio. Self measurement and reporting of waist circumference has been reported to be acceptable in recent epidemiological studies (Rimm *et al*, 1990; Chan *et al*, 1994) but better information will be needed about possible self-reporting bias, and ability to monitor changes with weight management. Proof of the value of waist circumference measurements in predicting health risks will require longitudinal follow-up of morbidity and mortality, however waist circumference is more highly associated with metabolic function than waist:hip ratio in adults (Houmard *et al*, 1994) and in children (Flodmark *et al*, 1994) and predicts myocardial infarction (Lapidus *et al*, 1984). The proposed Action Levels match the results of Chan *et al* (1994), who found progressively increasing relative risk of developing type 2 diabetes in men as waist circumference rose from 73.7-87.6 cm to 91.7-96.5 cm (relative risk = 2.2) and to those above 102.0 cm (relative risk = 12). Pouliot *et al* (1994) observed exponential increases in cardiovascular risk factors with waist circumference above 87 cm in men and 78 cm in women, which correspond to waist circumference of Action Level 1, and further risk factor increases with waist circumferences above Action Level 2. Proof of the value of waist circumference will require longitudinal follow up of morbidity and mortality. Longitudinal data from the Framingham study suggest that waist predicts mortality better than other anthropometric measures (Higgins *et al*, 1988).

CONCLUSIONS

Action Levels of waist circumference (measured using bony landmarks, midway between the iliac crests and the lowest ribs) identified in the present study could form the basis for health promotion to raise awareness, or to urge action in terms of weight reduction. The lower Action Level 1 of waist circumference 94 cm (men) and 80 (women) represents a threshold above which health risks are increase - particularly for young men (Chan *et al*, 1994; Must *et al*, 1992). Further weight gain and rise in waist circumference from Action Level 1 towards Action Level 2, should be prevented. The upper Action Levels 102 cm for men and 88 cm for women correspond with the point when symptoms of breathlessness and arthritis begin to develop from overweight, and health risks are such that medical consultation and active weight loss should be urged.

Table 4.1.1. Characteristics of subjects in determination sample and independent validation sample.

	Determination sample				Validation sample			
	Men ($n = 904$)		Women ($n = 1014$)		Men ($n = 86$)		Women ($n = 202$)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (years)	51.0	14.1	50.8	14.0	44.9	14.1	37.5	12.6
Weight (kg)	75.9	13.7	65.9	14.5	80.3	16.1	66.6	13.5
Height (cm)	170.7	7.0	158.2	6.5	174.9	6.6	162.2	6.7
BMI (kg/m^2)	26.0	4.1	26.3	5.5	26.2	4.7	25.4	5.3
Waist (cm)	93.3	11.9	82.0	12.3	93.1	14.8	80.1	14.2
Hips (cm)	100.5	7.7	101.7	11.1	99.8	8.1	101.7	9.8
Waist:hip ratio	0.93	0.07	0.80	0.07	0.93	0.09	0.79	0.10

BMI = body mass index

Table 4.1.2. Number of subjects in determination sample in different categories of body mass index and waist:hip ratio.

	Body mass index (kg/m^2)				
	<20	20-	25-	>30	Total
Men					
0.72-<0.95	99	241	201	23	564
0.95-1.13	0	52	183	105	340
Total	99	293	384	128	904
Women					
0.65-<0.80	61	267	143	54	525
0.80-1.20	13	139	186	151	489
Total	74	406	329	205	1014

Table 4.1.3. Number of men and women in different categories of body mass index and waist:hip ratio in groups classified by waist circumference Action Level in determination sample and validation sample.

	Determination sample		Validation sample	
	Men n=904	Women n=1014	Men n=86	Women n=202
Action Level 1				
Waist ≥94 cm for men and 80 ≥cm for women	422	512	24	88
With body mass index:				
≥25	389	437	16	81
<25	33	75	9	7
<25 but high waist:hip ratio	25	68	2	4
<25 and low waist:hip ratio*	8	7	0	3
Waist <94 cm for men and 80 <cm for women	482	502	61	114
With body mass index:				
<25	359	405	61	107
≥25	13	97	0	7
≥25 but high waist:hip ratio	113	83	9	7
≥25 and low waist:hip ratio†	10	14	2	0
Action Level 2				
Waist ≥102 cm for men and 88 ≥cm for women	210	292	35	50
With body mass index:				
≥30	116	184	33	30
<30	94	108	2	20
<30 but high waist:hip ratio	82	106	9	19
<30 and low waist:hip ratio*	12	2	0	1
Waist <102 cm for men and 88 <cm for women	694	722	55	156
With body mass index:				
<30	682	701	40	151
≥30	12	21	11	5
≥30 but high waist:hip ratio	8	19	0	1
≥30 and low waist:hip ratio†	4	2	0	0

High waist:hip ratio ≥0.95 for men and ≥0.80 for women; low waist:hip ratio <0.95 for men and <0.80 for women; *false positive subjects; †false negative subjects.

Table 4.1.4. False positive and false negative subjects and sensitivity and specificity for men and women in determination sample and in validation sample by waist circumference to identify those with body mass index and ≥25 or ≥30 and those with lower body mass index but waist:hip ratio ≥0.95 (men) or ≥0.80 (women).

Body mass index (kg/m^2)	Waist (cm)	False positive	False negative	Sensitivity (%)	Specificity (%)
Determination sample:					
Men (n = 904)					
25-	≥94	8/340	10/280	96.8	98.2
≥30	≥102	12/541	4/105	97.9	97.8
Women (n = 1014)					
25-	≥80	7/328	14/337	96.5	98.3
≥30	≥88	2/471	2/151	99.2	99.6
Validation sample:					
Men (n = 86)					
25-	≥94	0/38	2/32	94.1	100
≥30	≥102	0/49	0/15	100	100
Women (n = 202)					
25-	≥80	3/98	0/63	100	97.1
≥30	≥88	1/120	0/28	100	99.2

Sensitivity was calculated as true positives/(true positives + false negatives), specificity as true negatives/(true negatives + false positives).

Table 4.1.5. Studies reporting metabolic benefits of weight loss in groups with differing waist:hip ratios.

								% Changes in outcome measure				
									Cholesterol			
	Sex	*n*	Age (y)	Waist:hip ratio	Body mass index (kg/m^2)	Weight loss (kg)	Weight loss (%)	Trigly-ceride	Total	LDL	HDL	Treatment
Den Besten *et al* (1988)	F	8	37.0	0.74	61.6	9.6	10.9	-16.2	-7.4	NA	-7.4	Low calorie diet
Den Besten *et al* (1988)	F	7	36.0	0.82	34.6	10.8	11.4	-38.4	-10.8	NA	-13.0	Low calorie diet
Dennis *et al* (1993)	F	18	45.0	0.77	30.0	9.0	11.0	-22.5	-6.2	-9.3	+3.7	Low calorie diet
Dennis *et al* (1993)	F	32	44.0	0.87	31.0	9.2	11.2	-23.4	-1.0	0.0	+11.4	Low calorie diet
Kanaley *et al* (1993)	F	9	35.3	0.74	32.1	7.7	8.8	-8.4	NA	NA	+5.8	Low calorie diet and exercise
Kanaley *et al* (1993)	F	10	36.1	0.89	33.4	9.2	10.3	-20.7	NA	NA	+20.0	Low calorie diet and exercise
Lean *et al*†	F	30	51.5	0.75	28.1	6.0	8.1	-15.7	-5.6	-6.9	-0.6	Low calorie diet and slimming capsule‡
Lean *et al*†	F	16	57.6	0.84	28.9	5.2	7.1	19.8	-3.9	-3.2	+0.7	Low calorie diet and slimming capsule‡
Lean *et al*†	F	27	52.0	0.76	33.7	82	9.4	-8.3	-2.9	-2.7	-2.0	Low calorie diet and slimming capsule‡
Lean *et al*†	F	52	53.5	0.85	35.7	6.2	6.9	-17.1	-2.9	-1.6	+0.5	Low calorie diet and slimming capsule‡
Sönnichsen *et al* (1992)	M	40	49.7	1.02	41.4	6.4	6.8	-11.0	-16.5	-21.1	NA	Low calorie diet
Houmard *et al* (1994)	M	13	47.2	0.96	30.4	2.0	2.1	-20.3	-0.3	NA	+8.2	Exercise
Wing *et al* (1992)	M	101	37.3	0.97	31.0	9.8	10.2	-16.2	-9.8	NA	NA	Low calorie diet

NA = not available; LDL = low density lipoprotein; HDL = high density lipoprotein; †unpublished data; ‡proprietary food based capsule.

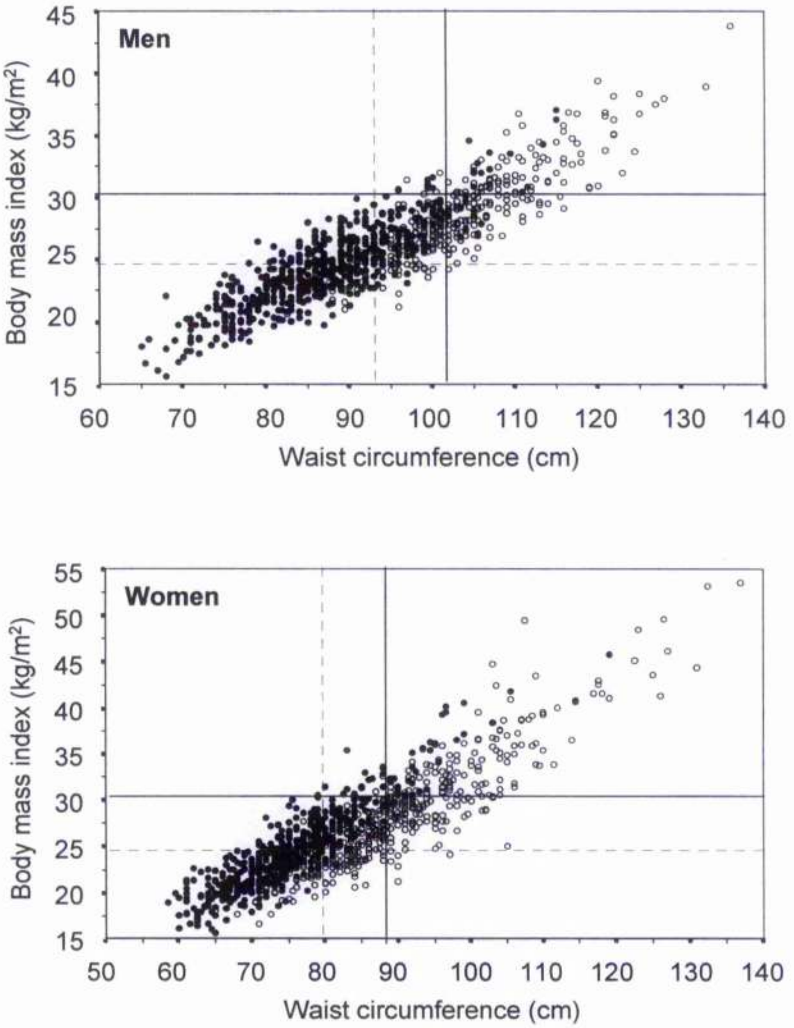


Figure 4.1.1. Relation between waist circumference and body mass index in men and in women from determination sample and the two Action Levels of waist circumference that identify subjects with body mass index ≥25 or ≥30 kg/m^2 and with waist:hip ratio ≥0.95 for men and ≥0.80 for women. Dotted line shows Action Level 1, solid line Action Level 2. O Waist:hip ratio ≥0.95 men, ≥0.80 women: false negative in upper left quadrant; ● waist:hip ratio <0.95 men, <0.80 women: false positives in lower right quadrant. Linear regression: body mass index = (0.307 × waist circumference) - 2.6 (men); body mass index = (0.394 × waist circumference) - 6.0 (women).

WAIST CIRCUMFERENCE AS A SCREENING TOOL FOR CARDIOVASCULAR RISK FACTORS: EVALUATION OF RECEIVER OPERATING CHARACTERISTICS (ROC)

This section has been peer reviewed and has been published as

Han TS, van Leer ME, Seidell JC, Lean MEJ. Waist circumference as a screening tool for cardiovascular risk factors: evaluation of receiver operating characteristics (ROC). *Obesity Research* 1996; **4**:533-47.

Collaboration with MORGEN project

ABSTRACT

Objective: To evaluate the receiver operating characteristics (ROC) to determine the cut-offs of waist circumference as a potential population directed screening tool for hypercholesterolaemia (≥6.5 mmol/l), low high density lipoprotein cholesterol (≤0.9 mmol/l), and hypertension (treated and/or systolic ≥160 and/or diastolic blood pressure ≥95 mmHg), in 2183 men and 2698 women aged 20-59 years selected at random from Dutch civil registries.

Main outcome measures: Height, weight, body mass index (BMI) waist circumference, total plasma cholesterol and high density lipoprotein cholesterol concentrations, and blood pressure.

Results: ROC curves showed that sensitivity equalled specificity at waist circumferences between 93-95 cm in men and 81-84 cm in women for identifying individual risk factors, and 92 cm in men and 81 cm in women for identifying those with at least one risk factor. Sensitivity and specificity were equal at levels between 61% to 69% for identifying individual risk factors, with positive predictions (56.8% in men and 37.8% in women) within 2% of those using previously defined 'Action Level 1' of waist circumference 94 cm in men and 80 cm in women (58.8% in men and 37.4% in women). Risk prediction by anthropometric methods is relatively low: ROC areas for identifying each risk factor by waist varied from 55 to 60%, and reached about 65% for identifying at least one risk factor. Height accounted for less than 0.3% of variance in waist circumference. Using BMI at 25 kg/m^2 gave similar prediction to waist, but its combination with waist did not improve predictive values.

Conclusions: Measurement of waist circumference 'Action Level 1' at 94 cm (37 inches) in men and 80 cm (32 inches) in women could be adopted as a simpler valid alternative to BMI for health promotion, to alert those at risk of cardiovascular disease, and as a guide to risk avoidance by self-weight management.

Key words: epidemiology, fat distribution, health, obesity, weight management

INTRODUCTION

Large waist circumference reflects both high body fatness (body mass index) and central fat distribution (waist to hip ratio) (**Chapter 4.1**; Lean *et al*, 1995). Waist circumference has also been shown to relate closely to the metabolically active intra-abdominal fat (Pouliot *et al*, 1994; Seidell *et al*, 1988), Després and his colleagues (1990) have suggested that waist circumference may be the most important anthropometric index of fat distribution as a predictor of cardiovascular risk, in preference to waist to hip ratio. We have proposed two 'Action Levels' of waist circumference for health promotion purposes, to identify subjects with increasing ('Action Level 1': men 94 cm, women 80 cm) or high ('Action Level 2': men 102 cm, women 88 cm) health risk (**Chapter 4.1**; Lean *et al*, 1995). These 'Action Levels' of waist circumference have been replicated in different populations and shown to classify individuals at increased cardiovascular risk both in men and women (**Chapter 5.2**; Han *et al*, 1995c).

The present study was designed to examine whether different criteria or 'cut-offs' of waist circumference are necessary to identify individuals who are at increased risks of different risk factors, i.e. hypercholesterolaemia (European Atherosclerosis Society, 1987; WHO MONICA Project, 1988), low plasma high density lipoprotein cholesterol (European Atherosclerosis Society, 1987), hypertension (WHO MONICA Project, 1988), and at least one of these risk factors. We are aware that total cholesterol/high density lipoprotein cholesterol ratio may give a better index of cardiovascular risk than single measures. This will be addressed in future study, but the present paper is limited to single measures and the category of any one risk factor includes both total cholesterol and high density lipoprotein cholesterol. The 'Action Levels' of waist circumference proposed on the basis of body mass index and waist to hip ratio by Lean *et al* (1995) were related to the cut-offs of waist circumference that identified the highest numbers of subjects with and without the risk factors, *i.e.* where sensitivity and specificity of prediction were equal for different risk factors (Sturmans, 1984).

METHODS

Subjects

A random sample of 2183 men and 2698 women aged 20-59 years was selected from the civil registries in Amsterdam, Maastricht and Doetinchem, as part of the MORGEN (monitoring risk factors and health in The Netherlands) project to determine the prevalence of risk factors for chronic diseases, and also other specific chronic conditions in a sample of the general population living in various parts of the Netherlands. The measurements were made in basic health service centres in Amsterdam (the capital city in the West), Doetinchem (a small town in the East) and Maastricht (a town in the South). To obtain equal numbers in each age group, the sample was stratified according to gender and five year age groups. The response rate was approximately 50% in Amsterdam and Maastricht, and 80% in Doetinchem.

Anthropometry

All measurements were made by trained investigators. Body weight in light clothes was measured to the nearest 0.1 kg, and height to the nearest 0.5 cm. Body mass index was calculated as weight/height^2 (kg/m^2). Waist circumference midway between lower rib and iliac crest, and hip circumference at the level of the great trochanters were measured in duplicate using flexible tape to the nearest mm (WHO Expert Committee, 1995).

Cardiovascular risk factors

Sitting blood pressure was measured using random zero sphygmomanometer, by technicians who had been trained by a physician. Small (9 x 18 cm), medium (size 12 x 23 cm) or large (15 x 33 cm) cuff was used to fit upper arms of different sizes. Systolic (first-phase Korotkoff) and diastolic (fifth-phase Korotkoff) blood pressure were measured twice on the left upper arm, and the average was used for analysis.

Total and high density lipoprotein-cholesterol were determined enzymatically using Boehringer test kit (Katterman *et al*, 1984). High density lipoproteins were isolated by precipitating apo-B containing lipoproteins with magnesium phosphotungstate described by Lopes-Virella *et al* (1977). This method used a mixture a 2 ml of plasma, 200 μl of sodium phosphotungstate solution, and 50 μl of $MgCl_2$. All cholesterol analyses were performed at the Clinical Chemistry Laboratory, University Hospital of Dijkzigt in Rotterdam, which is part of the standardization program (WHO Regional Lipid Center for Europe in Prague, Czechoslovakia, and the Centers for Disease Control in Atlanta, USA).

Analysis

The criteria for cut-offs of cardiovascular risk factors were selected before analysis, based on consensus figures from the European Atherosclerosis Society (1987) and the World Health Organization (1988). Hypercholesterolaemia was defined as plasma cholesterol ≥6.5 mmol/l (European Atherosclerosis Society, 1987; WHO MONICA Project, 1988), low high density lipoprotein-cholesterol as ≤0.9 mmol/l (European Atherosclerosis Society, 1987), and hypertension as systolic blood pressure ≥160 mmHg and/or diastolic blood pressure ≥95 mmHg and/or the use of antihypertensive agents (WHO MONICA Project, 1988).

Statistical methods

The numbers of subjects at different levels of waist circumference with or without cardiovascular risk factors were determined by cross tabulation, and these numbers were used to determine the receiver operating characteristics of waist circumference in the identification of risk factors. Sensitivity was defined as the percentage of the total number of subjects with risk factor who were identified correctly by high (above the cut-off level) waist circumference, and specificity as the percentage of the total number of subjects without risk factor who were correctly identified by low (below cut-off level) waist circumference. Positive prediction was calculated as the percentage of subjects with waist circumference above the cut-off level who had the risk factor, and negative prediction as the percentage of those with waist circumference below cut-off level who did not have the risk factor (Sturmans, 1984).

Sensitivity and specificity for predicting risk factor prevalence by various waist circumferences were plotted against waist circumference. The cut-offs where waist circumference identified the highest numbers of subjects with **and** those without the risk factors were obtained by interpolation from the intersect at which the lines of sensitivity and specificity crossed each other (*i.e.* where sensitivity equalled specificity) (Sturmans, 1984). The areas of the receiver operating characteristic (ROC) curves for waist circumference in identifying risk factors were examined using the modified equations of Hanley and McNeill (1982).

Adjustments for body mass index and waist to hip ratio were not made because of multicollinearity with waist circumference (Belsley *et al*, 1980). Height accounted for less than 0.3% of variance in waist circumference (**Figures 4.2.1a** & **b**), and was not subsequently used in analysis of waist circumference. Statistical analyses performed SAS computer programme (SAS Institute, Gary, USA).

RESULTS

Mean age, body mass index, hip circumference and total cholesterol were similar in men and women. Men had higher waist circumference, waist to hip ratio and blood pressure, and lower high density lipoprotein cholesterol than women (**Table 4.2.1**). Waist circumference correlated significantly (P <0.001) with body mass index (men: r = 0.860, women: r = 0.850) and waist to hip ratio (men: r = 0.84, women: r = 0.81). Body mass index also correlated significantly (P <0.001) with waist to hip ratio both in men (r = 0.64) and women (r = 0.51). The relationships between waist circumference and height (**Figures 4.2.1a** & **b**) were extremely weak, and therefore waist circumference was not adjusted for height.

The numbers (%) of subjects who had cholesterol ≥6.5 mmol/l were 323 (14.9%) in men and 401 (15.0%) in women, 564 (26.0%) men and 159 (6.0%) women had high density lipoprotein ≤0.9 mmol/l, 191 men (9.7%) men and 198 (7.3%) women were considered to be hypertensive, and there were 887 (40.6%) men and 657 (24.4%) women who had at least one of these risk factors.

The levels of waist circumference that correctly identified the maximum numbers of subjects with and without the risk factors, *i.e.* the highest value of (sensitivity + specificity)/2, were around 95 cm in men (**Figure 4.2.2a**) and 80 cm in women (**Figure 4.2.2b**). The **exact** cut-offs that identified the maximum numbers of subjects with and without the risk factors were obtained by interpolation from the point at which sensitivity crossed specificity. These cut-offs were very close to waist circumference at the proposed 'Action Level 1' (94 cm in men, 80 cm in women) in both men and women (**Tables 4.2.2a & b; Figures 4.2.3 & 4.2.4**): the cut-offs for identifying each risk factor tended to be a little higher than 'Action Level 1' in women, and below 'Action Level 1' in men, but the differences were mostly less than 2 cm. The cut-offs for identifying those with at least one risk factor in men (92 cm) were 2 cm below 'Action Level 1' (94 cm), but almost identical to 'Action Level 1' (80 cm) in women (80.6 cm).

The differences in sensitivity and in specificity between the cut-offs and 'Action Level 1' were within 10 % (within 5 % in most cases) of each other. The differences in positive and in negative predictions of risk factors were very small between these levels. Positive prediction of those with at least one or more risk factors was higher than that of each individual risk factor, both in men (56.8 %) and women (37.8 %), but negative predictions were slightly lowered (**Tables 4.2.2a & b**).

Table 4.2.3 shows that waist circumference 'Action Level 1' performed similarly to body mass index 25 kg/m^2 for identifying those with risk factors (positive prediction) and those without risk factors (negative prediction) both in men and women. Including subjects with waist circumference below 'Action Level 1' but whose body mass index was above 25 kg/m^2 did not further improve the prediction of cardiovascular risk factors. The cut-off of waist circumference for identifying at least one risk factor (92 cm) was used as the general cut-off for each individual risk, showed slightly better negative prediction but was less good in positive prediction than 'Action Level 1' (**Table 4.2.4**). The equivalent cut-offs of waist in women (80.6 cm) was not analysed further, since it was so close to 'Action Level 1' (80 cm).

The estimated areas of the receiver operating characteristic curves for waist circumference in identifying each risk factor varied between 55-60%, and about 65% for identifying at least one risk factor.

DISCUSSION

Waist circumference correlated highly (r >0.8; P <0.001 both in men and women) with body mass index and waist to hip ratio in the present study, and can identify those with a combination of high or low body mass index and high waist to hip ratio (**Chapter 4.1**; Lean *et al*, 1995). The 'Action Levels' of waist circumference for men and women were derived to indicate the need for weight management (**Chapter 4.1**; Lean *et al*, 1995), based on the conventional cut-off of body mass index 25 kg/m^2 or 30 kg/m^2 and waist to hip ratio in men 0.95 and 0.80 in women. These 'Action Levels' have been proposed for use in health promotion as likely to indicate increasing risks from obesity related complications, avoiding the need to calculate body mass index, or errors from inaccurate height measurement (**Chapter 3.1**; Lean *et al*, 1996). The present study provides justification for 'Action Level 1' (94 cm in men, 80 cm in women) on the ground that it is remarkably close to the cut-offs of waist associated with increased risk (92 cm in men, 80.6 cm in women) of any one or more major cardiovascular risk factors. On this basis, use of a cut-off of waist circumference allows prediction as good as body mass index for all the major cardiovascular risk factors, and for the total number of people at risk.

The cut-offs in the present study for men and women are different, since the derivation were based on relative risk within each sex. Our previous study of the same subject sample showed men and women have the same absolute prevalence of cardiovascular risk factors for a given waist circumference (**Chapter 5.2**; Han *et al*, 1995c). Pouliot *et al* have suggested a cut-off of waist circumference in predicting health risks of 100 cm both for men and for women (Pouliot *et al*, 1994). However, although a cut-off of 100 cm will give a valid cut-off for absolute level of risk, irrespective of gender, a larger number of women with risk of preventable disease would not be identified.

The areas of the receiver operating characteristic curves for waist circumference in identifying individual risk factors of 55-60% and at least one risk factor of 65% were thus relatively low, but similar to the level expected from other anthropometric measurements in identifying health risks (WHO Expert Committee, 1995). Using waist circumference as a tool to screen for risk factors would inevitably misclassify at least 35 % of subjects by falsely including subjects who have waist circumference above the cut-off but without risk factors, and excluding those whose waist circumference below the cut-off but with risk factors. The figures used as cut-offs for total cholesterol ≥6.5 mmol/l (European Atherosclerosis Society, 1987; WHO MONICA Project, 1988), for high density lipoprotein cholesterol ≤0.9 mmol/l (European Atherosclerosis Society, 1987) and for systolic ≥160 and diastolic blood pressure ≥95 mmHg (WHO MONICA Project, 1988) are widely used to indicate elevated cardiovascular risk, but fairly conservative. The yield of individuals who would fulfil risk factor criteria at a lower level of risk, e.g. high density lipoprotein ≤1.0 mmol/l, total cholesterol ≥5.2 mmol/l, would be greater than those identified by the risk factor levels employed in the present paper, and would lower the intersect where sensitivity equals specificity by waist circumference of about 3 cm (data not shown). We have examined the relationships between waist circumference and risk factors, including plasma triglyceride, elsewhere (**Chapter** 7; Han *et al*, 1997a). Unfortunately, plasma triglyceride, which relates closely to waist circumference, and metabolic risk, was not available for the present analysis.

It is theoretically possible that age might modify the amount of intra-abdominal fat at any given waist circumference. Examination of waist circumference for two separate age groups of 20-39 and 40-59 years showed that compared to the cut-off for the whole population (**Figures 4.2.3-4.2.4**), the intersect where sensitivity equalled specificity in predicting risk factors was about 3 cm lower in younger subjects, and 3 cm higher in older subjects in both sexes (data not shown). This observation agrees with other suggestions that higher body mass index is not strongly associated with coronary heart disease in older subjects. If the criteria used to define levels of risk were slightly lowered for younger subjects, and raised for older subjects (on the basis that for any given level of metabolic risk factor, younger subjects are more likely to develop premature cardiovascular disease), then the age specific cut-offs of the two age groups would be even further apart. On this basis, adopting lower waist circumference 'Action Level 1' for younger people - say 90 cm (35 inches) in men and 76 cm (30 inches) in women, could be justified.

Sensitivity and specificity are inversely related. The decision for choosing a cut-off depends on the purpose and potential use (WHO, 1995). Lowering the cut-off of waist circumference would increase sensitivity for risk identification, but include more subjects who do not have the risk factors (false positives). Selecting a higher cut-off would increase specificity, but more subjects who have the risk factors (false negatives) would be missed from screening for potential health risks. The figures for waist circumference 'Action Levels' (**Chapter 4.1**; Lean *et al*, 1995) were proposed to alert people to increasing health risks. Subjects with waist circumference below 'Action Level 1' do not need to lose weight but should be aware of potential health risks when their waist approaches this level, used as the first line of warning. In the range between 'Action Level 1' and 'Action Level 2', termed the 'Alert Zone' (94-102 cm in men, 80-88 cm in women), subjects should not further gain weight, with lifestyle modification such as increasing physical activity level, and some self-managed weight loss if possible. Patients in this waist range of 'Alert Zone' with problems like non-insulin-dependent diabetes mellitus, hypertension, or angina would benefit from more active weight loss. Above this range, termed the 'Action Zone'($\geq$102 cm in men, and $\geq$88 cm in women), every body should be urged to take action to seek professional help to achieve sustained weight loss and for risk factor screening.

Although justified by several lines of evidence, cut-offs are always slightly arbitrary. Increased risks of breast cancer in women (den Tonkelaar *et al*, 1995), type 2 diabetes in men (Chan *et al*, 1994), and other risk factors of diabetes and of heart disease (Pouliot *et al*, 1994) have been shown to associate with waist circumference levels that are remarkably close to the 'Action Level 1' both in men and in women, suggesting that waist circumference may have a wider value, but the present paper has concentrated on cardiovascular risk factors. Financial constraints could favour the choice of higher cut-offs to reduce screening costs for large numbers of subjects. Using lower cut-offs may have greater health benefits, particularly if young people can be alerted to a developing weight problem or adverse fat distribution, and thereby encouraged to prevent weight gain at an early age. It is now increasingly recognised that overweight is a disease *per se* (Stunkard, 1996), and preventing weight gain for those with waist circumference approaches the 'Action Level 1' (94 cm in men, 80 cm in women) may be more effective than attempting weight loss for those with waist circumference has reached the 'Action Zone' (≥102 cm in men, and ≥88 cm in women).

Because of the high correlations between waist circumference, waist to hip ratio and body mass index with one another, pairing these variables together in statistical analysis for adjustments would not be appropriate due to the effect of multicollinearity (Belsley *et al*, 1980). This was confirmed when body mass index and waist circumference were combined, with little more improvement in predictive values for identifying risk factors (**Table 4.2.3**). Most subjects with adverse risk factors have both waist circumference above 'Action Level 1' and body mass index above 25 kg/m^2. Conversely most subjects without risk factors have both waist circumference below 'Action Level 1' and body mass index below 25 kg/m^2. Combining body mass index and waist to hip ratio also gave no improvement of risk factor prediction over waist circumference alone (results not shown).

Earlier studies of body composition and body fat distribution to identify subjects at risk of cardiovascular disease and type 2 diabetes have mainly focused on body mass index and waist to hip ratio (Lapidus *et al*, 1984; Larsson *et al*, 1984). Recently, waist circumference has been recognised as a good measure of abdominal fat and particularly the more metabolically active intra-abdominal fat (Pouliot *et al*, 1994; Ross *et al*, 1992 & 1993; Seidell *et al*, 1988; Seidell *et al*, 1992). Large waist includes most overweight subjects either with or without central fat distribution (**Chapter 4.1**; Lean *et al*, 1995). Young and Gelskey (1995) have suggested that overweight subjects with low waist to hip ratio have similar risk factors as those who are overweight with high waist to hip ratio. However, the absolute size of intra-abdominal fat mass may be the critical factor (already increased by high body mass index), and this was not considered by these authors. It is possible that certain risk factors relate more to body mass index than to waist to hip ratio, but using the waist circumference for health promotion simplifies this problem. The term 'central obesity' is confusing, since distribution may be central of peripheral, independent of body mass index, whilst those with high body mass index all tend to a more central fat distribution. In relation to metabolic risk factors, waist circumference is consistently more indicative of complications than any other anthropometric methods (Chan *et al*, 1994; den Tonkelaar *et al*, 1995; Edwards *et al*, 1994; Giovannucci *et al*, 1995; Pouliot *et al*, 1994; Seidell *et al*, 1992), but the positive predictions of cardiovascular risk for waist circumference of about 15-40% individual risks are not particularly high. The classification of subjects' level of risk is improved when any one or more risk factor is included (and 60% in men and 40% in women). Risk not accounted for by anthropometric measures might be identified for health promotion from a family history of premature heart disease, non-insulin dependent diabetes mellitus or hypertension.

CONCLUSIONS

The waist circumference 'Action Level 1' proposed by Lean *et al* (1995) to indicate the need for weight management, reflecting both high body mass index and high waist to hip ratio, corresponded closely to the levels of waist circumference associated with increased risk of each individual cardiovascular risk factor and the combination of any one or more of these risk factors. 'Action Level 1' at 94 cm (37 inches) in men and 80 cm (32 inches) in women may be useful through health promotion with a message to avoid weight gain (and thus to avoid hyperlipidaemia or hypertension) as part of the measures designed to prevent cardiovascular disease. Application of the data in this study should be restricted to white populations only. Further validation for other ethnic groups such as blacks or Asians is required, since body density, fat distribution and stature may be different.

Table 4.2.1. Physical and metabolic characteristics of 2183 men and 2698 women.

	Men		Women	
	Mean	SD	Mean	SD
Age (years)	42.7	10.5	42.5	10.7
Weight (kg)	81.4	11.9	68.3	11.3
Height (cm)	177.9	7.4	165.1	6.8
Body mass index (kg/m^2)	25.7	3.4	25.1	4.2
Waist circumference (cm)	91.6	10.4	80.3	10.9
Hip circumference (cm)	101.7	6.4	102.1	8.3
Waist:hip ratio	0.90	0.07	0.79	0.07
Total cholesterol (mmol/l)	5.4	1.1	5.4	1.1
HDL cholesterol (mmol/l)	1.1	0.3	1.4	0.4
Systolic blood pressure (mmHg)	122.8	15.6	115.5	15.4
Diastolic blood pressure (mmHg)	77.8	10.4	74.1	9.9

HDL = high density lipoprotein.

Table 4.2.2a. Sensitivity, specificity, positive and negative risk factor predictions using waist circumference at 'Action Level 1' and at cut-offs where sensitivity = specificity to identify the highest numbers of subjects with and those without hypercholesterolaemia, low high density lipoprotein cholesterol and hypertension in 2183 men.

	Waist	Sensitivity		Specificity		Positive prediction		Negative prediction	
	cm	%	95% CI	%	95% CI	%	95% CI	%	95% CI
'Action Level 1'									
High cholesterol	94.0	58.2	54.9, 61.5	63.3	60.7, 65.9	21.6	18.9, 24.3	89.7	88.1, 91.4
Low HDL cholesterol	94.0	56.8	53.5, 60.1	66.2	63.6, 68.7	37.5	34.3, 40.8	81.0	78.9, 83.1
Hypertension	94.0	71.2	68.2, 74.2	63.1	60.5, 65.7	15.6	13.2, 18.0	95.8	94.7, 96.9
One or more risk factors	94.0	57.0	53.7, 60.3	72.1	69.6, 74.5	58.8	55.5, 62.1	70.6	68.1, 73.0
*Cut-off**									
High cholesterol	93.2	60.8	55.5, 66.1	60.8	58.6, 63.0	21.5	18.8, 24.2	90.0	88.4, 91.7
Low HDL cholesterol	92.6	61.5	57.5, 65.5	61.5	59.1, 63.9	36.7	33.7, 39.7	81.7	79.5, 83.9
Hypertension	95.2	67.2	60.5, 73.9	67.2	65.1, 69.3	16.7	14.0, 19.4	95.3	94.2, 96.4
One or more risk factors	92.0	64.6	61.5, 67.7	64.6	62.0, 67.2	56.8	53.8, 59.8	72.8	70.2, 75.4

HDL, high density lipoprotein; *cut-off, where sensitivity = specificity.

Table 4.2.2b. Sensitivity, specificity, positive and negative risk factor predictions using waist circumference at 'Action Level 1' and at cut-offs where sensitivity = specificity to identify the highest numbers of subjects with and those without hypercholesterolaemia, low high density lipoprotein cholesterol and hypertension in 2698 women.

	Waist	Sensitivity		Specificity		Positive prediction		Negative prediction	
	cm	%	95% CI	%	95% CI	%	95% CI	%	95% CI
'Action Level 1'									
High cholesterol	80.0	65.3	62.7, 68.0	58.4	55.9, 60.9	21.5	19.2, 23.8	90.6	89.1, 92.1
Low HDL cholesterol	80.0	65.2	62.6, 67.9	56.4	53.9, 58.9	10.0	8.3, 11.7	95.6	94.6, 96.7
Hypertension	80.0	79.8	77.5, 82.1	57.6	55.1, 60.2	13.0	11.9, 14.9	97.3	96.5, 98.1
One or more risk factors	80.0	66.5	62.1, 69.2	62.2	59.7, 64.6	37.4	34.7, 40.1	84.5	82.7, 86.4
*Cut-off**									
High cholesterol	81.0	61.9	57.2, 66.7	61.9	59.9, 63.9	21.4	19.0, 23.8	89.8	88.3, 91.3
Low HDL cholesterol	81.5	60.8	53.8, 67.8	60.8	58.9, 62.7	10.7	8.9, 12.6	95.6	94.6, 96.6
Hypertension	83.6	68.7	62.2, 75.2	68.7	66.9, 70.5	15.0	12.7, 17.3	96.5	95.7, 97.4
One or more risk factors	80.6	64.4	60.8, 68.0	64.4	62.3, 66.5	37.8	35.0, 40.6	83.7	81.9, 85.5

HDL, high density lipoprotein; *cut-off, where sensitivity = specificity.

Table 4.2.3. Positive and negative predictions of hypercholesterolaemia, low high density lipoprotein cholesterol, and hypertension in those with body mass index above 25 kg/m^2, or those with waist above 'Action Level 1' combined with those below 'Action Level 1' but with body mass index above 25 kg/m^2.

	Body mass index				*Combined			
	Positive prediction		Negative prediction		Positive prediction		Negative prediction	
	%	95% CI	%	95% CI	%	95% CI	%	95% CI
Men (2183)								
High cholesterol	19.5	17.3, 21.8	90.9	89.1, 92.7	21.5	18.7, 24.3	91.9	90.1, 93.7
Low HDL cholesterol	33.8	32.2, 37.6	83.9	81.6, 86.2	38.8	35.4, 42.2	84.3	82.0, 86.7
Hypertension	12.8	11.2, 15.1	96.6	95.4, 97.7	16.0	13.5, 18.5	97.1	96.0, 98.2
One or more risk factors	54.2	51.4, 57.1	74.7	72.0, 77.4	60.0	56.6, 63.4	76.0	73.3, 78.8
Women (2698)								
High cholesterol	20.9	18.5, 23.2	89.6	88.1, 91.2	22.5	19.8, 25.2	91.3	89.8, 92.9
Low HDL cholesterol	10.0	8.3, 11.8	95.5	94.4, 96.5	11.3	9.3, 13.3	95.7	94.6, 96.8
Hypertension	12.6	10.6, 14.5	96.5	95.7, 97.5	14.5	12.3, 16.8	97.6	96.8, 98.4
One or more risk factors	36.5	33.7, 39.2	83.0	81.1, 84.8	40.0	36.9, 43.1	85.5	83.6, 87.4

HDL = high density lipoprotein; *Subjects with waist circumference above 'Action Level 1' (94 cm in men and 80 cm in women) combined with those below 'Action Level 1' but with body mass index above 25 kg/m^2.

Table 4.2.4. Positive and negative predictions of subjects with and those without hypercholesterolaemia, low HDL cholesterol, and hypertension by waist circumference 'Action Level 1' (94 cm in men and 80 cm in women), or by cut-offs of waist circumference where sensitivity = specificity to identify the highest numbers of subjects with and without at least one risk factor (92 cm in men and 80 cm in women).

	'Action Level 1'				'Cut-off'			
	Positive prediction		Negative prediction		Positive prediction		Negative prediction	
	%	95% CI	%	95% CI	%	95% CI	%	95% CI
Men (2183)								
High cholesterol	21.6	18.9, 24.3	89.7	88.1, 91.4	21.0	18.5, 23.5	90.7	89.1, 92.4
Low HDL cholesterol	37.5	34.3, 40.8	82.0	78.9, 83.1	36.3	33.4, 39.3	82.5	80.3, 84.7
Hypertension	15.6	13.2, 18.0	96.1	94.7, 96.9	14.3	12.2, 16.4	96.2	95.1, 97.3
One or more risk factors	58.8	55.5, 62.1	70.7	68.1, 73.0	57.4	53.7, 59.8	72.8	70.2, 75.4
Women (2698)								
High cholesterol	21.5	19.2, 23.8	90.6	89.1, 92.1	21.5	19.2, 23.8	90.6	89.1, 92.1
Low HDL cholesterol	10.0	8.3, 11.7	95.7	94.6, 96.7	10.0	8.3, 11.7	95.7	94.6, 96.7
Hypertension	13.0	11.9, 14.9	97.2	96.5, 98.1	13.0	11.9, 14.9	97.2	96.5, 98.1
One or more risk factors	37.4	34.7, 40.1	85.5	82.7, 86.4	37.4	34.7, 40.1	85.5	82.7, 86.4

HDL = high density lipoprotein.

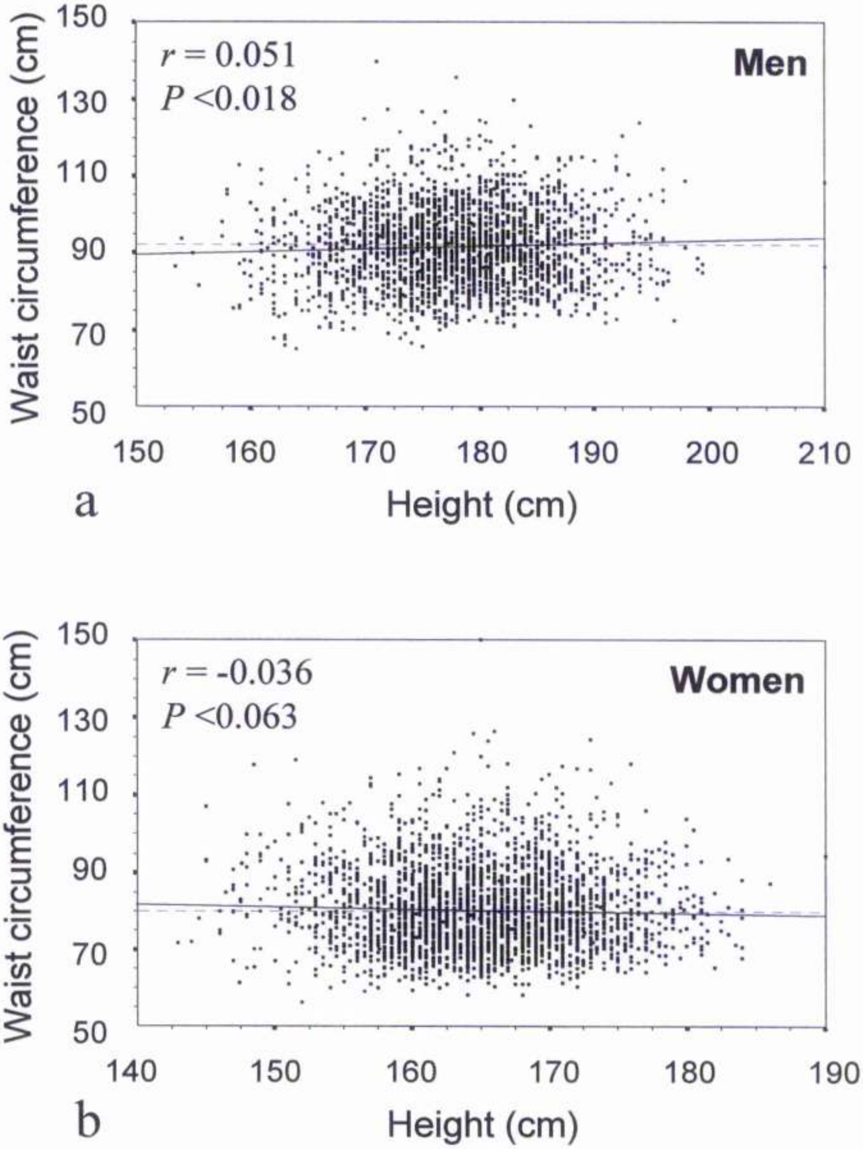


Figure 4.2.1. The relationship between waist circumference and height in 2183 men (a) and 2698 women (b), showing regression line (solid) and the line of zero correlation (dashed).

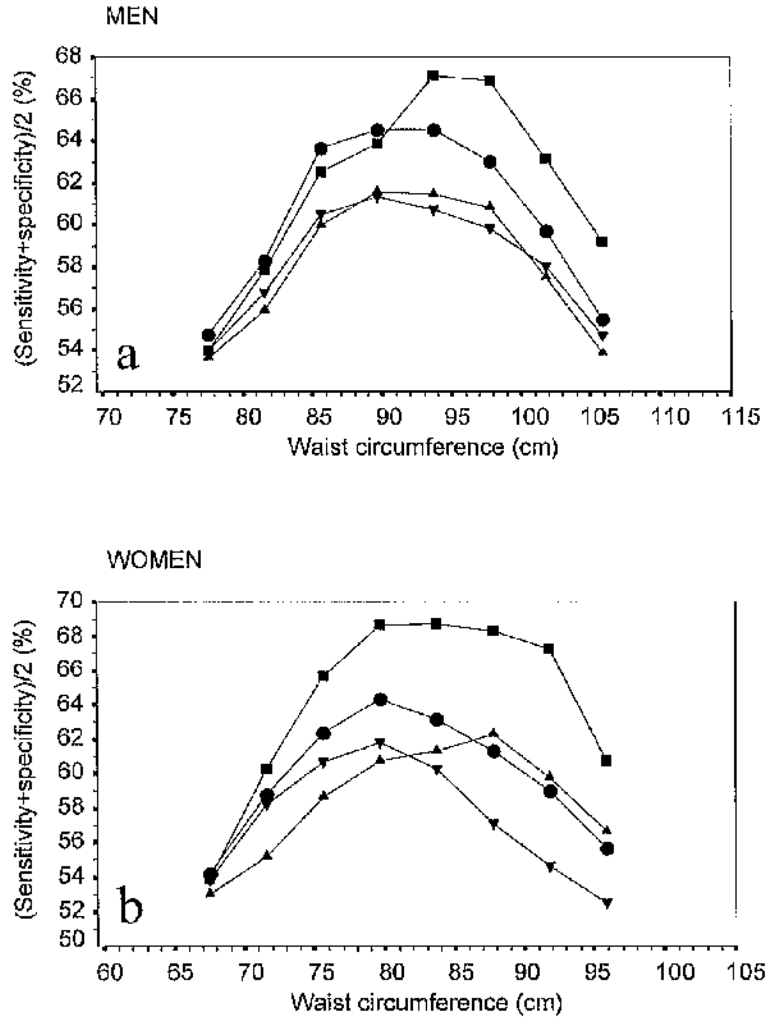


Figure 4.2.2. The average values of the sum of sensitivity plus specificity for waist circumference to identify subjects above or below 6.5 mmol/l of plasma cholesterol (▼), 0.9 mmol/l of high density lipoprotein cholesterol (▲), 160 mmHg of systolic blood pressure or 95 mmHg of diastolic blood pressure (■), and with or without any one or more cardiovascular risk factor (●) plotted against waist circumference in 2183 men (a) and 2698 women (b).

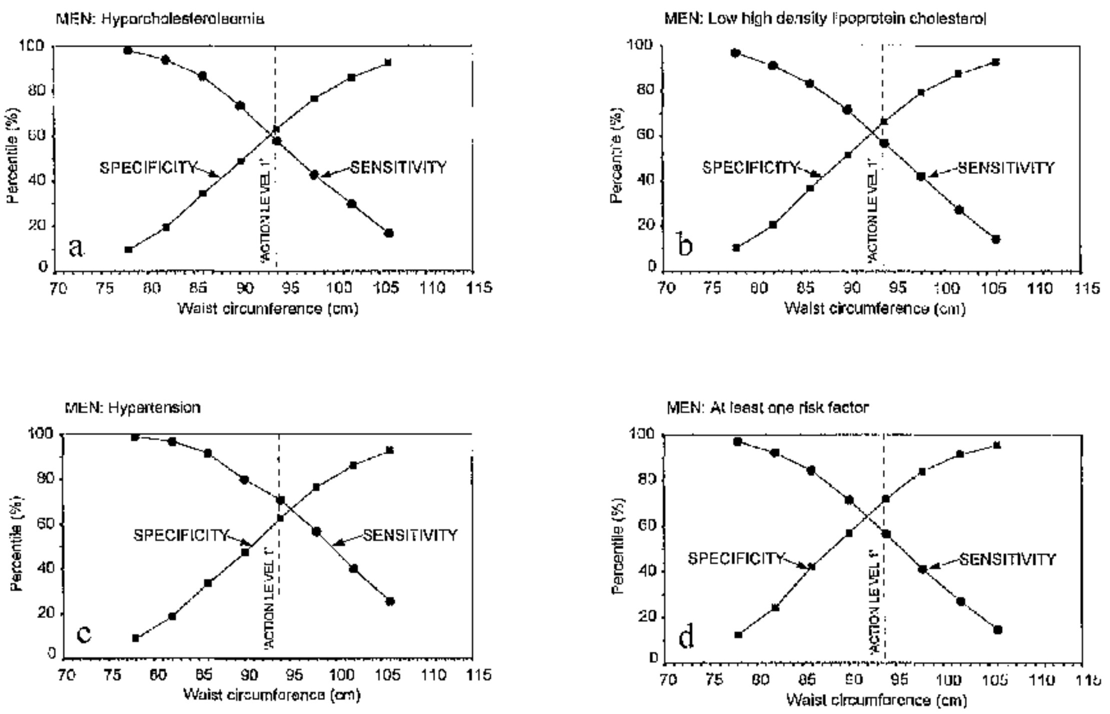


Figure 4.2.3. Percentile plot of sensitivity and specificity values for waist circumference to identify subjects above or below 6.5 mmol/l of plasma cholesterol (a), 0.9 mmol/l of high density lipoprotein cholesterol (b), 160 mmHg of systolic blood pressure or 95 mmHg of diastolic blood pressure(c) and with or without any one or more cardiovascular risk factors in 2183 men (d).

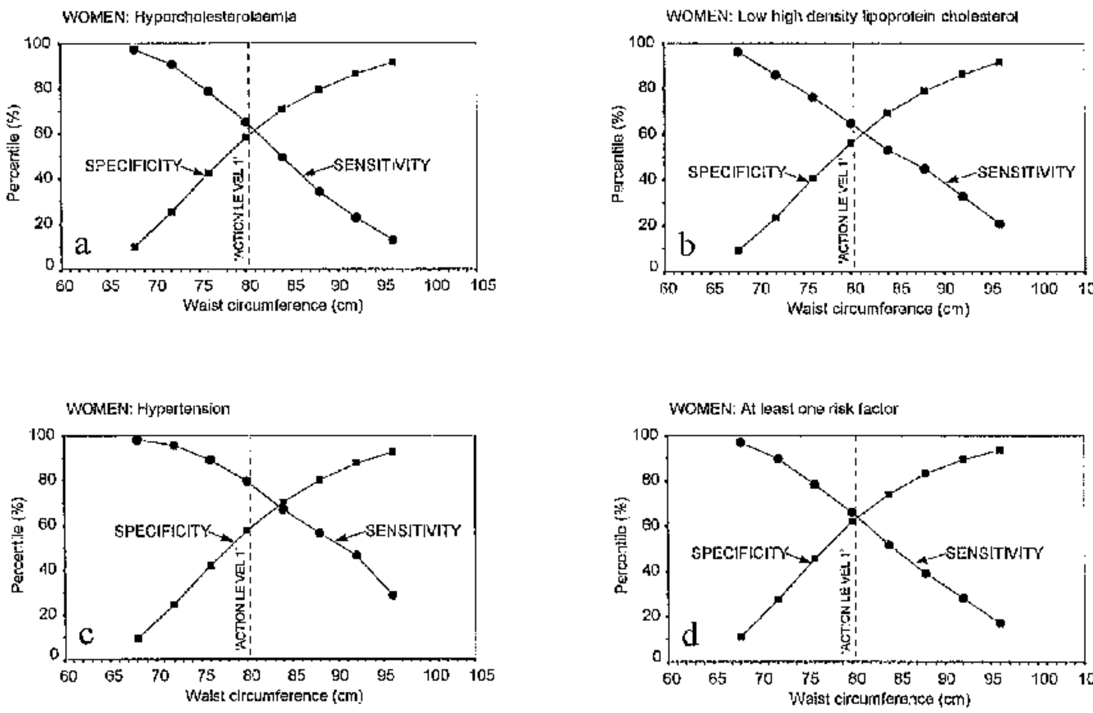


Figure 4.2.3. Percentile plot of sensitivity and specificity values for waist circumference to identify subjects above or below 6.5 mmol/l of plasma cholesterol (a), 0.9 mmol/l of high density lipoprotein cholesterol (b), 160 mmHg of systolic blood pressure or 95 mmHg of diastolic blood pressure(c) and with or without any one or more cardiovascular risk factors in 2698 women (d).

— 4.3 —

THE INFLUENCES OF HEIGHT AND AGE ON WAIST CIRCUMFERENCE AS AN INDEX OF ADIPOSITY

This section has been peer reviewed and has been published as

Han TS, Seidell JC, Currall JEP, Morrison CE, Deurenberg P, Lean MEJ. The influences of height and age on waist circumference as an index of adiposity in adults. *International Journal of Obesity* 1997; **21**:83-89.

Han TS, Seidell JC, Lean MEJ. Waist circumference remains useful predictor of coronary heart disease. *British Medical Journal* 1996; **312**:1227-28. [Letter]

Collaboration with MORGEN project

ABSTRACT

Objective: To assess the influences of height and age on the differences in waist circumference between individuals of different stature.

Subjects: 3319 males and 4358 females from four studies in the UK and the Netherlands.

Measurements: Waist circumference, body weight, height, and age.

Results: Linear regression analysis of $\log_{10}$ height as the independent variable on $\log_{10}$ waist as the dependent variable was used to determine the optimal index power (OIP) (^{P}) to minimise the influence of height in the relationships of waist/height^P. Six out of eight samples of men and women had OIP of height not significantly different from zero, with the remaining two groups had OIP between 0.15-0.58, indicating that height had very limited influence on the differences in waist circumference measurement between individuals. Age adjustment increased the relationship between waist and height, with OIP of 0.19-0.89 in men and 0.02-0.58 in women. Without age adjustment, height explained 0.3-3.5% and 0.1-2.5% variance in waist in men and in women respectively, and the corresponding variances were 0.4-7.5% in men and 0.0-2.6% in women with age adjustment. A similar analysis of weight and height showed the OIP of height in weight/height^P ratio ranged from 1.32-2.25 in men, and 0.87-1.74 in women without age adjustment, and from 1.47-2.24 in men and 1.25-1.96 in women with age adjustment.

Conclusion: Height and age had limited influences on the differences in waist between Caucasian subjects of different stature. Waist alone may be used to indicate adiposity or to reflect metabolic risk factors. In contrast, the influence of height on body weight is important.

Keywords: body mass index, cardiovascular disease, epidemiology, fat distribution, obesity, stature

INTRODUCTION

Body mass index (BMI) relates highly to total body fatness by densitometry (**Chapter 3.1**; Lean *et al*, 1996; Deurenberg *et al*, 1991), and has been widely used to indicate risks of overweight related morbidity and mortality (Royal College of Physicians, 1983). More recent understanding of the importance of the more metabolically active abdominal fat mass, particularly intra-abdominal fat mass, resulted in many ratios being proposed as anthropometric indicators, which include waist measurement as the dominant variable, since waist circumference or diameter is highly related to abdominal fat mass (Han *et al*, 1995b; Seidell *et al*, 1989a; Pouliot *et al*, 1994; Ross *et al*, 1992; Ross *et al*, 1993, van der Kooy *et al*, 1993). Height has been used as the denominator of abdominal fat mass indicators in efforts to eliminate a presumed relationship between waist circumference and stature Kannel *et al*, 1991; Valdez *et al*, 1991; Richelson *et al*, 1995; Higgins *et al*, 1988). Another proposed index involving height is the abdominal sagittal diameter/height ratio, to indicate subjects with increased metabolic risk factors (Richelson *et al*, 1995). The initial rationale for deriving ratios with waist measurement as the numerator was that metabolic risk factors are related more highly to central fat distribution than to total body fat, which is mainly located in areas other than the abdomen. The ratio waist to hip was thus developed, using the hip circumference to control for subcutaneous body fatness or body size and to accentuate the relationship with fat distribution. The ratio of waist to thigh was derived, since the size of the thigh reflects muscularity. More recently, it has been suggested that it is the absolute amount of intra-abdominal fat which influences health risk, not the distribution pattern (Kahn, 1993).

The present study aimed to determine the influences of height and age on the differences in waist circumference between individuals of different stature from four separately recruited Caucasian samples from Scotland and The Netherlands, based on the principles for determining adiposity (Khosla and Lowe, 1967).

METHODS

The principles for developing anthropometric ratios to indicate adiposity

Anthropometric ratios such as weight for height are derived so that differences in the variable of interest between individuals can be compared, while the influences of other structural variables are eliminated (Khosla and Lowe, 1967; Benn, 1971). Since body weight correlates significantly with height, taller individuals are generally heavier than shorter ones. Thus in order to compare the differences in adiposity (the variable of interest) between individuals it is the relative weight that matters, so differences in height must be eliminated. A simple method described by Khosla and Lowe to determine the optimal index power of height (^{P}) in the relationship weight/height^P for a set of individuals is to regress $\log_{10}$ height (independent variable) on $\log_{10}$ weight (dependent variable). The regression coefficient (β) of $\log_{10}$ height obtained in the equation is the optimal index power (^{P}) of height in the weight/height^P ratio, at which the differences of the derived ratio between subjects are dependent on body weight and uncorrelated with height (Khosla and Lowe, 1967).

An example from one of the male groups (MORGEN) in the present study shows that weight correlates positively (r = 0.441; P <0.001) with height. After logarithmic transformation, $\log_{10}$ height is used as independent variable and $\log_{10}$ weight as the dependent variable in linear regression analysis, to obtain the equation: $\log_{10}$ weight = **1.57** $\times$ $\log_{10}$ height - 1.62. The regression coefficient **1.57** is the optimal index power of weight/height$^{1.57}$ ratio: weight/height$^{1.57}$ has a zero correlation with height in this sample (**Table 4.3.3**). The conventional BMI (weight/height^2) had a low correlation with height (r = -0.140) in this sample.

Subjects and measurements

Four separate samples of 4881 Dutch men and women from the MORGEN study and 384 from Wageningen body composition studies, and 1918 Scots from the Glasgow MONICA study and 494 from the Glasgow body composition studies, had anthropometry measured following essentially identical standard protocols (WHO, 1989). Waist circumference was measured with flexible tape to the nearest mm, midway between the lateral iliac crest and lowest rib, at the end of gentle expiration. Weight in light clothes was measured to the nearest 100 g, and height barefoot and head in the horizontal Frankfort plane using a stadiometer to the nearest 0.5 cm. All measuring instruments were calibrated with standards before use. The men and women from the MORGEN and MONICA studies were randomly recruited from the general population, so they are expected to be representative of entire population of the Netherlands and Glasgow respectively. The other two groups were healthy subjects recruited for a variety of physiological measurements, and exhibit wide ranges of anthropometric variables (**Chapter 3.1**; Lean *et al*, 1996; Deurenberg *et al*, 1991).

Analysis

The relationships between height and waist circumference and body weight were assessed by linear regression analysis. Optimal index powers (^{P}) in the ratios waist/height^P or weight/height^P for men and for women in the four separate studies were obtained from the linear regression coefficient between $\log_{10}$ height (independent variable) and $\log_{10}$ waist or $\log_{10}$ weight (dependent variable).

RESULTS

Subjects had wide ranges of age and anthropometry (**Table 4.3.1**). Dutch men and women were taller than the Scots. Mean waist circumference and body mass index were similar between the groups of men and between the groups of women, except that Glasgow women had higher values than the other female groups.

Plots from the MORGEN study show a significant (P <0.001) positive correlation between weight and height (**Figures 4.3.1a** & **b**), and this correlation decreased towards zero (**Figures 4.3.2a** & **b**) when height^2 was incorporated as its denominator (BMI). On the other hand, waist circumference alone had an almost zero correlation with height in both sexes (**Figures 4.3.3a** & **b**). Similar trends were observed in the other three studies (**Table 4.3.2**).

Height correlated significantly (P <0.001) with body weight in men (r range 0.375 to 0.505) and in women (r range 0.165 to 0.320) (**Table 4.3.2**). As expected, the correlation of height with BMI (weight/height^2) was much less, and tended to be negative both in men (r range -0.213 to 0.064), and in women (r range -0.248 to -0.054). In the same subjects from all four studies, height explained no more than 1.6% of variance of waist circumference in seven out of eight groups, except the male group from the Glasgow MONICA study which was slightly higher (r^2 = 3.3%). The relationship between height and weight or waist became more positive when adjusted for age (**Table 4.3.2**), while age adjustment appeared not to alter the relationship between height and BMI.

Without age adjustment, regression analysis to derive the optimal index power in the waist/height^p ratio (**Table 4.3.3**) showed this value was close to zero in all the samples studied, indicating that there was no significant linear relationship between height and waist measurement. Only the MONICA men and MORGEN men did the 95% confidence interval excluded zero. The MORGEN sample was large enough to analyse by decades of age, and this resulted in optimal power between 0.36 to 0.58 in men and 0.06 to 0.26 in women.

Weight/height ratio included for comparison showed one group with optimal index power of height reasonably close to the index power 2 of body mass index in men. The remaining three groups had optimal index power of height close to 1.5. Three out of four female groups had optimal index power of height close to 1, and the remaining group value was close to 1.5. The index power 2 (namely BMI) was included within the 95% confidence intervals for three of the eight ten year age bands in the MORGEN sample.

In the samples studied, age correlated positively (P <0.001) with waist circumference (r range from 0.214 to 0.612 in men, and 0.197 to 0.464 in women), and age correlated negatively (P <0.001) with height (r range -0.200 to -0.508 in men, and -0.216 to -0.269

in women), which in cross sectional studies could reflect either height loss through ageing or alternatively a secular trend towards a taller population (van Leer *et al*, 1992. The possible influence of age on the relationship between waist circumference or weight and height was examined by stratifying subjects into four groups, 20-29, 30-39, 40-49, and 50-59 years in the MORGEN sample (**Table 4.3.3**), or by regression analysis of $\log_{10}$ height on $\log_{10}$ waist or on $\log_{10}$ weight adjusting for age in each sample (**Table 4.3.4**), showed the optimal index powers increased to between 0.19-0.89 in men and between 0.02-0.58 in women for waist/height^p, and between 1.47-2.38 in men and between 1.25-1.96 in women for weight/height^p.

Correlations between height and waist/height^p ratios with various index powers of height ranging from 0 to 1 in the MORGEN study group showed the weakest correlation coefficients occurred when the index powers (^{p}) of waist/height^p were between 0.25-0.50 in men and 0-0.25 in women. Age adjustment for the MORGEN sample of all ages showed the weakest correlation between waist/height^p and height were 0.50 in men and 0.25 in women (**Table 4.3.5**).

Without age adjustment, height explained 0.3-3.5% and 0.1-0.8% of variance of waist circumference in men and in women respectively, and the corresponding values with age adjustment were 0.4-7.5% in men and 0.0-2.6% in women.

The relationship between waist circumference and height was further analysed in the MORGEN sample. Subjects were stratified into two groups according to the waist circumference 'Action Level 1' (94 cm in men, 80 cm in women) (**Chapter 4.1**; Lean *et al*, 1995). **Table 4.3.6** shows that there were weak but significant associations between height and waist circumference in men and women with waist circumferences below the 'Action Level '. The proportion of variance in the waist circumference explained by height in those with a waist circumference above the 'Action Level ' was 0.64% in men and 0.03% in women.

DISCUSSION

Without age adjustment, the optimal index power of height in the waist/height^p ratio was consistently close to zero in both sexes of all eight samples studied. Men generally have higher optimal index powers than women in the weight/height^p relationship, indicating a greater influence of height on weight in men. Adjustment of age by regression analysis or by dividing the population into ten year age bands accentuated the relationship between height and waist or weight. By stratifying subjects from the MORGEN sample according to 'Action Level 1' (94 cm in men and 80 cm in women) (**Chapter 4.1**; Lean *et al*, 1995), we have shown that height correlated slightly higher with waist in those with a waist circumference below 'Action Level 1', but in those with a waist above 'Action Level 1', the proportion of age adjusted variance in waist circumference explained by height was only 0.64% (P <0.05) in men and 0.03% (P = not significant) in women (**Table 4.3.6**). Thus in those who need weight management, height does not importantly influence variations in waist circumference. In their studies of coronary heart disease in relation to the physique of London busmen, Heady *et al* (1961) came to the same conclusion that height adjustment for waist circumference was not necessary, since little difference was made to the results.

In mathematical terms, the indices reflecting adiposity such as BMI and waist circumference respectively should have a zero correlation with height to eliminate the influence of stature. Deurenberg *et al* (1991) have demonstrated that weigh/height^p index as a measure of body fatness does not necessarily have to be completely independent of height, due to significant correlation between body fatness and height. The relationship between intra-abdominal fat mass and height in 20 women, aged 20-51 years, has been examined in a study using magnetic resonance imaging (**Chapter 4.4**; Han *et al*, 1997b). Intra-abdominal fat mass did not correlate significantly with height (r^2 = 1.3%, P = 0.40), but correlated more highly with waist circumference (r^2 = 77.8%, P <0.001), abdominal sagittal diameter (r^2 = 77.4%, P <0.001) transverse diameter (r^2 = 77.4%, P <0.001) and body mass index (r^2 = 72.3%, P <0.001) than with waist hip ratio (r^2 = 32.5%, P <0.05). Ratios of waist/height^p of different index powers did not increase upon the variance in intra-abdominal fat mass explained by waist circumference alone. Neither intra-abdominal fat mass ($P = 0.40$) nor waist circumference ($P = 0.31$) related significantly to height in these women.

It is perhaps surprising to find that physical stature as indicating by height has such limited influence on waist circumference. However waist circumference is a body dimension which contains *relatively* little bone (only the spine). The relationship in men is very weak and limited to certain age bands. In women, spinal shortening from osteoporosis could tend to increase waist circumference, and this may be more pronounced so reducing any relationship in older and shorter women, thus accounting for the inverse relationships (**Figure 4.3.3b**).

Practicality must be taken into account when deriving anthropometric indices (WHO, 1995), to establish the advantage of ratios or other complex expressions over the single variable alone, ease of computation of the ratio (Benn, 1971), the availability of the variables for measurement, and reliability of measurement in the field. If the measurements for a ratio are easy to obtain and it gives much better prediction than the single variable, then using the ratio is justified. For example, many attempts (Khosla and Lowe, 1967; Benn, 1971) have been made to derive new indices of adiposity from weight and height in order to better the body mass index (weight/height^2), but most of these ratios are sex or population specific, as confirmed in the present study. By consensus, weight/height^2 is still the ratio of choice. Although the BMI does not have a perfect zero correlation with height, it is a reasonable approximation for many purposes, the index power 2 is rather conveniently remembered, and easy to calculate. Although weight/height^2 ratio was originally derived from Caucasian populations it is commonly used to assess body weight in other ethnic groups. Examination of its validity may still be required in these groups.

The slight differences in optimal index powers between the four study populations (**Table 4.3.3**) could be explained by systematic differences in anthropometric measurements between centres, although no such differences in technique have been identified, and the same measurement protocols were used (WHO, 1989). Alternatively there may be minor morphological differences between the populations related to factors such as physical activity, diet, and use of hormone replacement therapy. There were differences in age ranges, the Wageningen sample contained subjects up to 83 years, whereas other samples were mostly less than 70 years (MONICA and Glasgow) or less than 60 years (MORGEN). All subjects studied were older than 18 years. With age adjustment, optimal index powers between samples became more similar to each other. The influence of age on the association between waist circumference and height in the large MORGEN sample was relatively small and probably not of practical importance for most purposes.

Studies of magnetic resonance imaging (**Chapter 4.4**; Han *et al*, 1997b; Ross *et al*, 1992; Ross *et al*, 1993) and computed tomography (Pouliot *et al*, 1994) showed waist explained 80- 90% of variance in total body fat. We have shown that large waist circumference alone identifies most subjects with high BMI or high waist to hip ratio (**Chapter 4.1**; Lean *et al*, 1995), and can be used to predict total body fat as measured by densitometry, at least as well as by the conventional skinfold method and without bias when fat distribution is altered (**Chapter 3.1**; Lean *et al*, 1996). Waist circumference also relates strikingly to cardiovascular risk factors (Pouliot *et al*, 1994; **Chapter 5.2**; Han *et al*, 1995c). Waist/height ratio correlates tightly with BMI (r >0.9). Seidell *et al* (1992) have previously shown waist/height ratio was no better than waist/thigh ratio or waist circumference alone in predicting cardiovascular risk factors.

CONCLUSIONS

Height and age have limited influence on the differences in waist circumference between individuals of different stature. Waist alone may be a useful indicator of adiposity in either men or women in Caucasian populations without the need to adjust for height. This is in contrast to measures of weight, where a positive correlation with stature necessitates adjustment for height, as the conventional weight/height^2 ratio for BMI.

Table 4.3.1. Characteristics of subjects from the Netherlands and Scotland.

	Dutch				Scots					
Study	MORGEN		Wageningen		MONICA		Glasgow		All studies	
n (M/F)	2183/2698		146/238		904/1014		86/408		3319/4358	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Men										
Age (years)	42.7	10.5	45.9	17.4	51.0	14.1	44.9	14.1	45.2	12.6
Waist (cm)	91.6	10.4	93.3	10.8	93.3	11.9	93.1	14.8	92.2	11.0
Weight (kg)	81.4	11.9	81.1	11.7	75.9	13.7	80.3	16.1	79.8	12.8
Height (m)	1.78	0.07	1.80	0.08	1.71	0.07	1.75	0.07	1.76	0.08
BMI (kg/m^2)	25.7	3.4	25.1	3.4	26.0	4.1	26.2	4.7	25.8	3.6
Women										
Age (years)	42.6	10.7	36.9	17.5	50.8	14.0	43.5	14.3	44.3	12.9
Waist (cm)	80.3	10.9	82.6	12.0	82.0	12.3	86.3	14.3	81.4	11.8
Weight (kg)	68.3	11.3	67.8	12.9	65.9	14.5	75.9	16.9	68.4	13.0
Height (m)	1.65	0.07	1.68	0.07	1.58	0.07	1.61	0.06	1.6.3	0.07
BMI (kg/m^2)	25.1	4.2	24.2	4.7	26.3	5.5	29.2	6.5	25.7	4.9

BMI = body mass index

Table 4.3.2. Correlation coefficients, unadjusted and age adjusted, between height (independent variable) and body weight, body mass index, and waist circumference in Dutch and Scottish men and women.

Study	*n*	Weight		BMI		Waist	
		Crude	Age adjusted	Crude	Age adjusted	Crude	Age adjusted
Men							
MORGEN	2183	0.441***	0.490***	-0.140***	-0.063**	0.051*	0.193***
Wageningen	146	0.375***	0.361***	-0.213**	-0.159^{ns}	-0.150^{ns}	0.061^{ns}
MONICA	904	0.505***	0.506***	0.064^{ns}	0.090**	0.186***	0.275***
Glasgow	86	0.385***	0.497***	-0.018^{ns}	0.085^{ns}	0.068^{ns}	0.245*
Women							
MORGEN	2698	0.252***	0.304***	-0.248***	-0.198***	-0.036^{ns}	0.054**
Wageningen	238	0.173**	0.283***	-0.248***	-0.119^{ns}	-0.057^{ns}	0.162*
MONICA	1014	0.320***	0.338***	-0.054^{ns}	-0.011^{ns}	0.059^{ns}	0.137***
Glasgow	408	0.165***	0.238***	-0.188***	-0.113*	-0.088^{ns}	-0.001^{ns}

*P <0.05; **P <0.01; ***P <0.001; ns = not significant

Table 4.3.3. Optimal index powers (when height has zero correlation with the derived ratios) of the denominator height in the ratios of waist/height and weight/height derived from regression analysis of $\log_{10}$height on $\log_{10}$waist, and on $\log_{10}$weight respectively, with four age bands in the MORGEN study.

		Waist/height^p			Weight/height^p		
Study	*n*	OIP	SE	95% CI	OIP	SE	95% CI
Men							
MORGEN							
20-29	333	0.36	0.13	0.10, 0.62	1.72	0.15	1.42, 2.02
30-39	544	0.56	0.11	0.33, 0.78	1.85	0.14	1.57, 2.13
40-49	672	0.38	0.10	0.18, 0.58	1.68	0.13	1.48, 1.93
50-59	634	0.58	0.10	0.39, 0.77	1.86	0.12	1.63, 2.10
All ages	2183	0.15	0.06	0.03, 0.26	1.57	0.07	1.44, 1.70
Wageningen	146	-0.42	0.22	-0.86, 0.02	1.32	0.25	0.82, 1.82
MONICA	904	0.58	0.10	0.39, 0.78	2.25	0.12	2.01, 2.50
Glasgow	86	0.17	0.44	-0.71, 1.05	1.78	0.49	0.82, 2.75
Women							
MORGEN							
20-29	448	0.10	0.14	-0.17, 0.37	1.14	0.18	0.79, 1.49
30-39	644	0.23	0.11	0.02, 0.44	1.45	0.13	1.19, 1.71
40-49	817	0.26	0.11	0.04, 0.48	1.23	0.13	0.97, 1.48
50-59	789	0.06	0.11	-0.15, 0.28	1.15	0.13	0.89, 1.41
All ages	2698	-0.11	0.06	-0.23, 0.01	1.04	0.07	0.90, 1.18
Wageningen	238	-0.18	0.22	-0.61, 0.26	0.87	0.28	0.32, 1.42
MONICA	1014	0.22	0.11	0.00, 0.43	1.74	0.15	1.45, 2.03
Glasgow	408	-0.38	0.21	-0.79, 0.02	0.89	0.27	0.35, 1.42

OIP = optimal index power

Table 4.3.4. Optimal index powers (when height has zero correlation with the derived ratios) of the denominator height in the ratios of waist/height and weight/height derived from regression analysis of $\log_{10}$height on $\log_{10}$waist, and on $\log_{10}$weight respectively, with age adjustment.

		Waist/height^p			Weight/height^p		
Study	*n*	OIP	SE	95% CI	OIP	SE	95% CI
Men							
MORGEN	2183	0.51	0.05	0.41, 0.62	1.82	0.07	1.68, 1.95
Wageningen	146	0.19	0.24	-0.28, 0.67	1.47	0.29	0.89, 2.05
MONICA	904	0.89	0.10	0.69, 1.09	2.38	0.13	2.12, 2.63
Glasgow	86	0.73	0.34	0.05, 1.41	2.24	0.44	1.38, 3.11
Women							
MORGEN	2698	0.17	0.06	0.06, 0.29	1.25	0.07	1.11, 1.39
Wageningen	238	0.58	0.21	0.16, 0.99	1.49	0.29	0.92, 2.06
MONICA	1014	0.54	0.11	0.31, 0.76	1.96	0.16	1.65, 2.27
Glasgow	408	0.02	0.20	-0.38, 0.41	1.39	0.27	0.87, 1.92

OIP – optimal index power

Table 4.3.5. Correlations between height and waist/height^p ratios of various index powers in the MORGEN study in all subjects with and without age adjustment, and in four different age bands.

Age group		Correlation coefficients				
(years)	*n*	Waist	Waist/Ht$^{0.25}$	Waist/Ht$^{0.50}$	Waist/Ht$^{0.75}$	Waist/Ht
<u>Men</u>						
20-29	333	0.140*	0.038^{ns}	-0.064^{ns}	-0.164**	-0.259***
30-39	544	0.192***	0.104*	0.013^{ns}	-0.077^{ns}	-0.166***
40-49	672	0.138***	0.046^{ns}	-0.047^{ns}	-0.139***	-0.228***
50-59	634	0.228***	0.130**	0.029^{ns}	-0.074^{ns}	-0.174***
All ages	2183	0.051*	-0.042^{ns}	-0.132***	-0.220***	-0.303***
†All ages	2183	0.193***	0.098***	0.001^{ns}	-0.096***	-0.191***
<u>Women</u>						
20-29	448	0.024^{ns}	-0.058^{ns}	-0.139**	-0.216***	-0.289***
30-39	644	0.080*	-0.009^{ns}	-0.097*	-0.184***	-0.266***
40-49	817	0.077*	-0.001^{ns}	-0.076*	-0.151***	-0.224***
50-59	789	-0.018^{ns}	-0.063^{ns}	-0.143***	-0.220***	-0.293***
All ages	2698	-0.036^{ns}	-0.112***	-0.186***	-0.258***	-0.325***
†All ages	2698	0.054**	-0.028^{ns}	-0.109***	-0.188***	-0.263***

**P* <0.05; ***P* <0.01; ****P* <0.001; ns = not significant; ns = not significant; Ht, height; †age adjusted.

Table 4.3.6. Correlation coefficients between height and waist circumference in subjects identified by waist circumference 'Action Level 1', in the MORGEN study (94 cm in men, 80 cm in women).

Age (y)	Men				Women			
	Waist <94 cm		Waist ≥94 cm		Waist <80 cm		Waist ≥80 cm	
	n	*r*	*n*	*r*	*n*	*r*	*n*	*r*
20-29	285	0.198**	48	-0.001	363	0.123*	85	-0.125
30-39	386	0.202***	158	-0.043	442	0.153**	202	-0.038
40-49	374	0.138**	298	0.092	417	0.120*	400	0.032
50-59	267	0.157*	367	0.120*	259	0.102	529	-0.022
All ages	1312	0.053	871	0.049	1481	0.056*	1217	-0.040
†All ages	1312	0.192***	871	0.080*	1481	0.131***	1217	-0.018

**P* <0.05; ***P* <0.01; ****P* <0.001; †age adjusted.

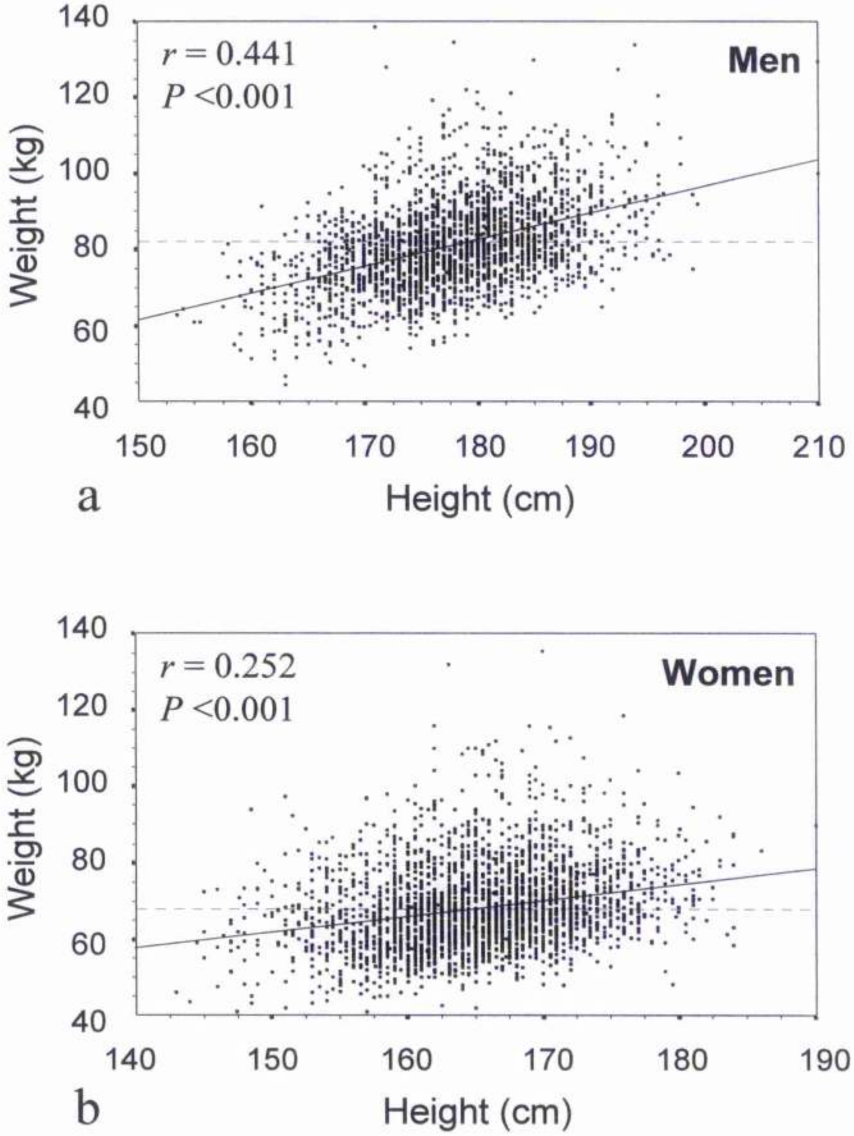


Figure 4.3.1. The relationship between body weight and height in men 2183 (a) and 2896 women (b), showing the regression line (solid) and line of zero correlation (dashed).

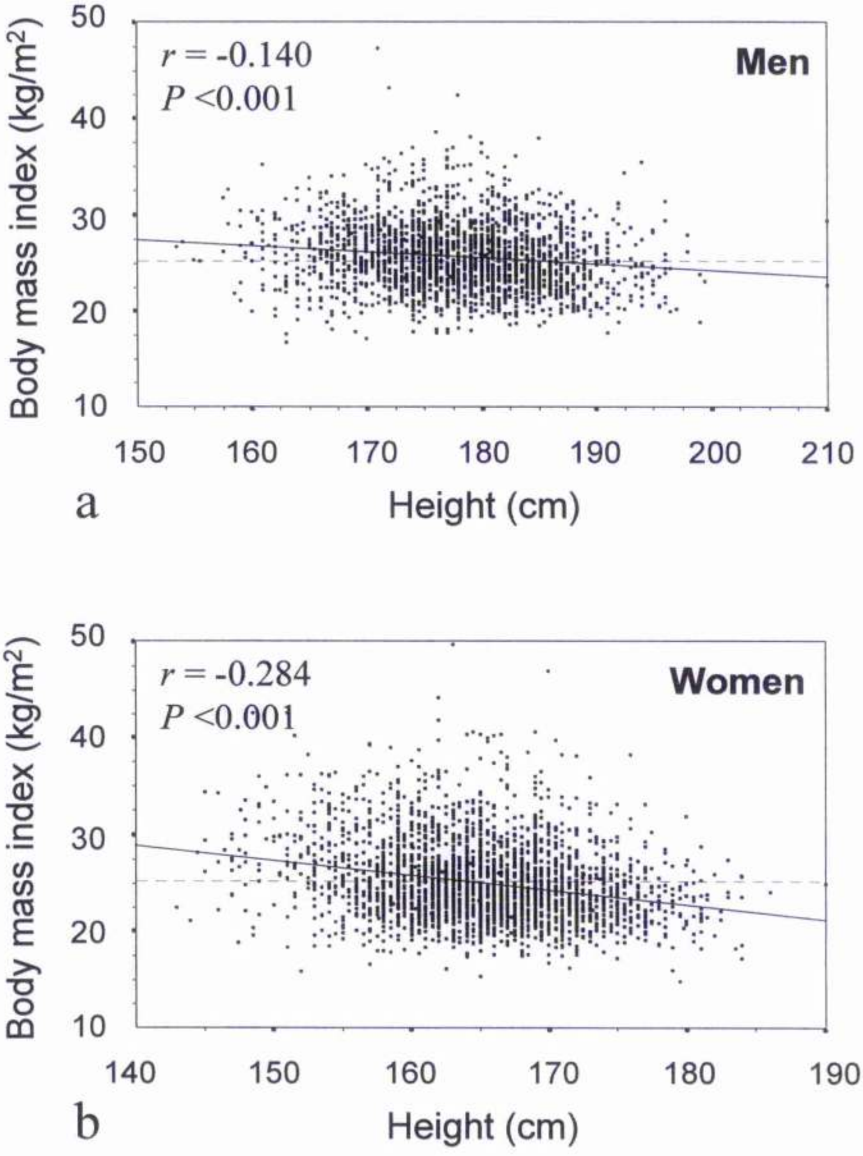


Figure 4.3.2. The relationship between body mass index and height in 2183 men (a) and 2896 women (b), showing the regression line (solid) and line of zero correlation (dashed).

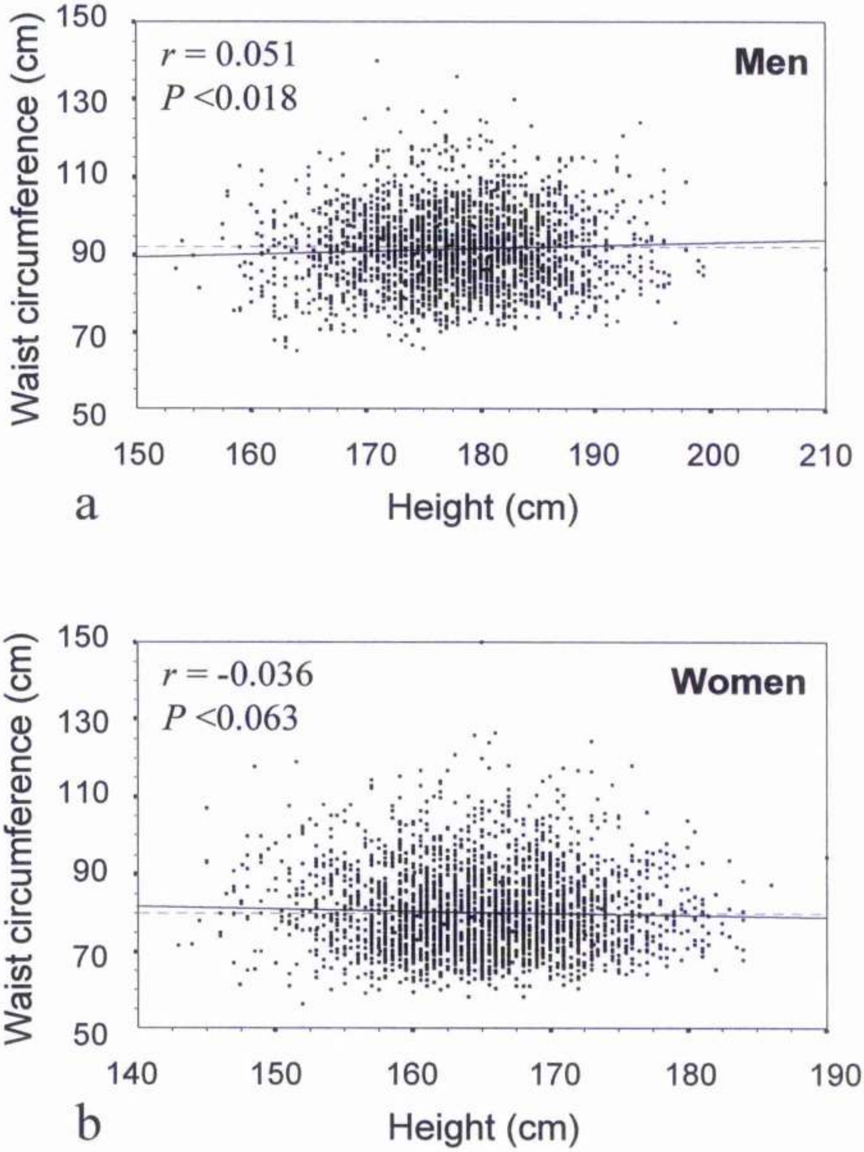


Figure 4.3.3. The relationship between waist circumference and height in men 2183 (a) and 2896 women (b), showing the regression line (solid) and line of zero correlation (dashed).

— 4.4 —

PREDICTING INTRA-ABDOMINAL FATNESS BY MAGNETIC RESONANCE IMAGING AND COMPUTERISED TOMOGRAPHY FROM ANTHROPOMETRIC MEASURES FOR HEALTH PROMOTION: THE INFLUENCE OF STATURE

This section has been peer reviewed and will be published as

Han TS, McNeill G, Seidell JC, Lean MEJ. Predicting intra-abdominal fatness from anthropometric measures: the influence of stature. *International Journal of Obesity* 1997; (in press).

Collaboration with Professor JC Seidell

ABSTRACT

Objective: To investigate the influence of height on the relationships between the intra-abdominal fat and anthropometric measures.

Subjects: Twenty healthy female volunteers aged 20 to 51 years from Aberdeen, and 71 men and 34 women aged 19 to 85 years from Nijmegen, The Netherlands.

Outcome measures: Intra-abdominal fat volumes by magnetic resonance imaging (MRI) in Aberdeen and cross-sectional areas at L4-L5 level by computerised tomography (CT) in Nijmegen, height, body mass index (BMI), waist circumference, waist sagittal and transverse diameters, waist to hip ratio, and skinfolds.

Results: In the MRI study the women with BMI 20-33 kg/m^2, waist circumference 62-97 cm, height 148-172 cm, and intra-abdominal fat volume 0.07-2.66 kg, waist circumference gave the highest correlation of simple indices with intra-abdominal fat volume, explaining 77.8% of variance. Single cross-sectional MRI cuts predicted volume with r = 0.94-0.99. Height in various levels of index power was not related to waist circumference, waist diameters, BMI, or skinfolds and did not improve prediction of intra-abdominal fat volume or of cross-sectional intra-abdominal fat area at any level. The CT study of men and women with BMI 18-32 kg/m^2 and 19-38 kg/m^2, waist circumference 71-112 cm and 74-125 cm, height 158-197 cm and 151-182 cm, and intra-abdominal fat area 13-274 cm^2 and 19-221 cm^2 respectively, height also had little influence on the relationships of intra-abdominal fat area with waist circumference or with any other indices of adiposity in linear or quadratic model. Compared to younger subjects, intra-abdominal fat area was higher in older subjects for a given waist.

Conclusion: Height does not importantly influence the differences in measures of adiposity or intra-abdominal fat volume in women, or intra-abdominal fat area in both sexes. Age does influence the prediction of intra-abdominal fat from waist circumference, but waist circumference alone has a predictable simple relationship with intra-abdominal fat volume or area, which is likely to relate to the prediction of health risk for health promotion.

Key words: body fat distribution, cardiovascular disease, computerised tomography, health promotion, height, magnetic resonance imaging, obesity.

INTRODUCTION

Increasing international concern about obesity, and its rising prevalence (Gregory *et al*, 1990; Bennett *et al*, 1995) and the recognition of the independent importance of body fat distribution has stimulated interest in identifying or predicting those at greatest health risk. For the purpose of health promotion directed at the general public, a single measurement of waist girth has been proposed as an indicator for alerting people to increased health risks associated with both total fatness and intra-abdominal fat accumulation (**Chapter 4.1**; Pouliot *et al*, 1994; Lean *et al*, 1995). We have shown that differences in waist circumferences between subjects are virtually unaffected by differences in heights, particularly amongst those who need weight management, namely waist above 94 cm in men, 80 cm in women (**Chapter 4.3**; Han *et al*, 1996b). These conclusions are not entirely new. In their studies of body shape and related health risk of London busmen, Morris and colleagues initially adjusted the size of trouser waist (proxy for waist circumference) for height (Morris *et al*, 1956), but in subsequent studies which also included the measurement of waist circumference, these authors realised that height adjustment made little difference in the comparisons of waist circumference between subjects of different stature (Heady *et al*, 1961). Sanders (1959) came to the same conclusion that height should be ignored when comparing differences in skinfold thicknesses, since there was no relationship between the two variables.

A recent study of a mixed group of 16 men and 31 women suggested that the cross-sectional area of intra-abdominal fat (in a single computerised tomography cut at the L4-L5 level) related slightly more highly with waist to height ratio ($r = 0.83$) than waist circumference alone ($r = 0.75$). A separate study of 97 men and 60 women found that intra-abdominal fat area was related linearly to waist in women but quadratically in men, and that the total variance was lower in men than in women (Schreiner *et al*, 1996).

The present study examined the influence of stature on the relationships between measures of adiposity and intra-abdominal fat volume estimated from the three dimensional volume measured by magnetic resonance imaging in women, and intra-abdominal fat area measured by computerised tomography in both sexes.

METHODS

Subjects

From larger studies of the influence of intra-uterine growth on fat distribution in 110 women in Aberdeen (Han, 1994), twenty healthy premenopausal women agreed to take part in detailed body composition assessment using magnetic resonance imaging. Data from a previous study in The Netherlands of body composition using computerised tomography scans in 71 men and 34 women in whom structural abnormalities had been excluded, referred to the Radiodiagnostic Institute of the University hospital in Nijmegen (Seidell *et al*, 1987), were analysed.

Intra-abdominal fat volume using magnetic resonance imaging

Intra-abdominal fat volume was measured by magnetic resonance imaging (Aberdeen Mark II, 0.08 Tesla). The pulse sequence technique using inversion/saturation recovery, with gain factor of four, repetition time of 1000 ms, and slice thickness of 20 mm, was used to synthesise the images in order to distinguish fat from other tissues. Intra-abdominal fat areas were determined from four cross-sectional images of equal distance between xiphisternum and anterior iliac crest, traced by hand using the computer 'mouse'. The number of pixels were converted to Système Internationale units from calculated values of x (3.15 mm) and y (3.95 mm) axes of the computer screen. Fat volume was calculated using a truncated cone model (Kvist *et al*, 1988) and then converted to fat mass assuming adipose tissue contains 80% of fat, 2% protein, 18% of water with negligible minerals (Garrow, 1974), with corresponding densities of 0.900, 1.34 and 0.993 kg/l (Siri, 1961), giving an average adipose tissue density of 0.9255 kg/l. Thus fat mass was converted from adipose tissue by a factor of $0.9255 \times 80\%$.

Intra-abdominal fat area using computerised tomography

Methodology has been described in detail by Seidell *et al* (1987). In brief, a single scan was made at the level of fourth-fifth lumbar vertebrae using computerised tomography scanner (Siemens UB Med, Germany). Data from the scans were analysed using histogram-based volumetric analysis technique to determine fat area set at the range of -150 to -50 Hounsfield units. The area of intra-abdominal fat was obtained using a light pen cursor through the muscles separating the subcutaneous and intra-abdominal fat.

Anthropometry

In the magnetic resonance imaging study, weight in light clothes was measured to the nearest 100 g, and height was measured barefoot with head in the horizontal Frankfort plane, using a stadiometer to the nearest 0.1 cm. Waist circumference midway between the lateral lower ribs and the iliac crest, and hip circumference at the widest part over the greater trochanters were measured according to standard protocols (World Health Organisation, 1989). Waist sagittal and transverse diameters were measured by pelvimeter (CMS Weighing Ltd, London) at the same level as for waist circumference, in standing position to the nearest mm. Skinfold thicknesses were measured at biceps, triceps, subscapular, and supra-iliac using skinfold calipers (Holtain, Crymych, UK). All measuring instruments were calibrated with standards before use. In the computerised tomography study, measurements of weight and height were obtained using similar methods. Waist circumference was measured at the umbilical level, and hip circumference was taken from the widest level. Two skinfold thicknesses at the sites of abdomen and supra-iliac crest were measured (Seidell *et al*, 1987).

Statistical analysis

Multiple linear regression analysis was performed to determine the relationships between measures of adiposity and intra-abdominal fat measures. Analyses used the SPSS statistical package (SPSS Inc., version 6.1.1, Chicago, Illinois).

RESULTS

Magnetic resonance imaging study

Subjects' characteristics are shown in **Table 4.4.1**. The body mass index distribution was similar to that of the British population (Gregory *et al*, 1990; Bennett *et al*, 1995). All four cross-sectional intra-abdominal fat areas correlated highly with the intra-abdominal fat volume. The area at L4, just above the iliac crest gave the lowest prediction ($r = 0.94$) and that at the 2/3 distance from xiphisternum to anterior iliac crest gave the highest ($r = 0.99$). **Table 4.4.2** shows that intra-abdominal fat areas between xiphisternum and iliac crests and intra-abdominal fat volume correlated highly and similarly with all measurements including waist circumference, and with body mass index but less well with waist to hip ratio or other anthropometric ratios. In this single sex study, dividing waist by height did not improve prediction of cross-sectional fat area compared to waist circumference alone, at every level between the xiphisternum and iliac crest. Waist circumference measured at the umbilical level was used instead of that measured between lowest rib margin and iliac crest in the analysis with intra-abdominal fat and the influence of height gave almost identical results (data not presented). In a larger study of 110 women which included the magnetic resonance imaging study (Han, 1994), waist circumference measured at the umbilical level (mean = 87.3, SD 15.5 cm) was 10% (mean difference = 8.0, SD 4.3 cm) bigger than that at the standardised level (World Health Organisation, 1989) midway between lowest rib margin and the iliac crest (mean = 79.3, SD 13.4 cm). Multiple linear regression analysis showed that the addition of age (t value for age = -0.308, $P = 0.762$) did not change the relationships between waist circumference and intra-abdominal fat volume. **Table 4.4.3** shows that height did not significantly correlate with intra-abdominal fat volume or any other indices of adiposity. Waist:height^p ratios of different levels of index power (p) for height were calculated. Waist circumference alone (waist:height^0) (**Figure 4.4.1a**) was related more closely to intra-abdominal fat volume than waist to height ratio (waist:height^1) (**Figure 4.4.1b**). Logarithmic or quadratic transformation showed waist to height ratio produced no further improvement in predicting intra-abdominal fat volume over waist alone (data not shown). **Table 4.4.4** shows that waist to height ratios of different levels of index power did not improve correlations with intra-abdominal fat volume over waist circumference alone.

Computerised tomography study

Subject characteristics are shown on **Table 4.4.5**. Compared to women in the magnetic resonance imaging study (**Table 4.4.1**), women in the computerised tomography study were older, and had similar body mass index (26.0 kg/m^2 *versus* 25.2 kg/m^2) but larger waist circumference (94.6 cm *versus* 78.6 cm). The difference in waist circumference between the women in the two studies is likely to result from different landmarks being used (umbilical for computerised tomography study, midway between lowest rib margin and iliac crest in magnetic resonance imaging study), and the difference would be much less if the same level were used (see result section of the magnetic resonance imaging study). Multiple linear regression analysis in **Table 4.4.6** shows that age was significantly related to intra-abdominal fat area in both sexes and to indices of adiposity in women only. The addition of height to the model did not significantly improve prediction in either sex. Low correlation between body mass index and age in men was partly explained by their non-linear relationship, weight increased up to 55 years and then decreased (figure not presented).

Table 4.4.7 shows that waist to height ratio was similar to waist circumference alone in predicting intra-abdominal fat area in men and women. Adjusting for age using partial correlation analysis increased all significant correlations between intra-abdominal fat area and all anthropometric indices except waist to height ratio (decreased) in men. Thus waist to height ratio and waist circumference were similar in prediction of intra-abdominal fat area after age adjustment. In women, all significant correlations decreased when adjustment was made for age. Subjects were stratified into two age groups at 50 years (**Table 4.4.8**). Variances were determined using curve estimation to see if there were curvilinear relationships between intra-abdominal fat area and waist circumference or waist to height ratio. There were slight differences in variances between the linear and quadratic relationships, and only men aged ≥50 years showed any evidence for difference between waist and waist to height ratio. The data set is too small to be confident that this is a real result.

Figures 4.4.2a & b show, for men and women separately, that dividing the subjects into two groups above and below 50 years, intra-abdominal fat area was linearly related to waist circumference. For a given waist circumference, younger men had significantly lower intra-abdominal fat area than older men. The gradients between the two age groups in women were not significantly ($P > 0.05$) different from each other.

DISCUSSION

The magnetic resonance imaging study in healthy female volunteers confirms the robust prediction of intra-abdominal fat volume from a simple waist circumference. The results on three-dimensional fat volume strengthens the data obtained from our study of single cut computerised tomography in men and in women separately. Neither waist circumference nor any other indices of adiposity nor intra-abdominal fat volume correlated with height. Therefore dividing indices by height to create ratios would violate the principle for deriving indices of adiposity (Benn, 1971). There may be separate influence of height on health risks, independent of body fat, but height does not contribute in measurement of intra-abdominal fat or fatness.

For use in health promotion, waist alone is already becoming established as a better predictor of risk factors related to body fat than more complicated ratios, such as waist to hip ratio or waist to height ratio, firstly because of ease of communication, and secondly because it is at least as powerful in predicting risk (**Chapter 5.2**; Han *et al*, 1995c) and mortality (Higgins *et al*, 1988) as the ratios. We have previously demonstrated a lack of association between height and waist circumference (**Chapter 4.3**; Han *et al*, 1996b; Han *et al*, 1997c). Changes in waist circumference have been shown to correlate ($P < 0.05$) with changes in intra-abdominal fat ($r = 0.81$) (Lemieux *et al*, 1996a), and changes in a variety of cardiovascular risk factors including total cholesterol ($r = 0.31$), low density lipoprotein cholesterol ($r = 0.35$) and blood pressure

($r = 0.26$) in women (**Chapter 7**; Han *et al*, 1997a). Changes in waist to hip ratio were not related to changes in either intra-abdominal fat (Lemieux *et al*, 1996a) or changes in cardiovascular risk factors (**Chapter 7**; Han *et al*, 1997a; Lemieux *et al*, 1996a).

Suggestions that a 'waist to height ratio' should be used in health promotion have been made, based on a study of single computerised tomography image just above the iliac crest (L4-L5) in a mixed group of 16 men and 31 women (Ashwell *et al*, 1996). However, it may not be appropriate to analyse men and women together, since the intercepts for the two sexes were significantly different (Ashwell *et al*, 1996). Our present computerised tomography analysis, combining 71 men and 34 women produced a small difference in the opposite direction: intra-abdominal fat area at L4-L5 correlated higher with waist circumference alone ($r = 0.79$, $r = 0.77$ after age adjustment) than with waist to height ratio ($r = 0.77$, $r = 0.72$ after age adjustment). Pouliot *et al* (1994) analysed 81 men and 70 women separately, and found waist circumference correlated with intra-abdominal fat area measured by computerised tomography at L4-L5 similarly to our single magnetic resonance images ($r = 0.87$) in women, and a correlation of 0.77 in men. Treuth *et al* (1995) observed a correlation of 0.84 between intra-abdominal fat area and waist circumference in women. These authors came to the same conclusion as ours, recommending the use of waist circumference as an index for intra-abdominal fat accumulation and associated morbidity. Waist sagittal diameter gave similar results to waist circumference in the present magnetic resonance imaging study.

In the present study, the close correlations between the volume and single cuts of intra-abdominal fat justify the use of a single scan in larger studies in terms of time and costs. **Table 4.4.2** shows that the best single scan was at the level of 2/3 the distance between xiphisternum and anterior iliac crest, approximately at the L2-L3 level in most subjects with $r^2 = 0.98$. The present study of magnetic resonance imaging had a relatively small sample of 20 women but the small sample size was compensated for by multiple scans, thus the results would be expected to be more robust than single scans. A recent study of magnetic resonance imaging (Abate *et al*, 1997) in 49 men showed similar results with best prediction of volume from a single cut at L2-L3 ($r^2 = 0.85$).

Intra-abdominal fat area was linearly related to waist circumference (**Table 8**) in both sexes, therefore the present study did not support the findings of Schreiner *et al* (1996), who observed a quadratic relationship in men. Age had important effects on fat distribution. When the subjects were divided into two age groups separated at 50 years in either sex, the gradients of the relationships between intra-abdominal fat area and waist circumference were significantly different in men (**Figure 4.4.2a**), but not in women (**Figure 4.4.2b**), namely for a given waist circumference, men above 50 years had significantly more intra-abdominal fat than those below 50 years. Significant differences in women of different age group might emerge if more extreme age groups could be compared, for example those above 60 versus those below 40 years. Similarly, it was observed that for a given body mass index, older subjects tended (not significant) to have more intra-abdominal fat than younger ones (data not presented). Lemieux *et al* (1996b) found similar results and have proposed higher cut-offs of waist circumference for younger people (below 40 years) to identify those with an intra-abdominal fat area above 130 cm^2. However, separate cut-offs in different age groups could only be justified if evidence is produced to indicate different associations of health risk with the same amount of intra-abdominal fat at different ages. Furthermore, other factors could influence intra-abdominal fat deposition, including illnesses such as non-insulin dependent diabetes mellitus, smoking and alcohol drinking. Separate cut-offs for these people might give greater predictive accuracy, but would complicate the whole issue in terms of health promotion directed at the general public.

CONCLUSIONS

Waist circumference alone explained 78% of the variance in intra-abdominal fat volume by magnetic resonance imaging in women, and there was no further improvement using waist:height^p ratios of different levels of index power. In both men and women, height did not greatly influence the relationship between intra-abdominal fat area by computerised tomography. In men, the slope of the relationship between intra-abdominal fat area and waist circumference was greater in those over 50 years than those under 50 years, so a given waist circumference is associated with more intra-abdominal fat area in older people than younger people. A similar trend was observed in women, but the difference in slopes was not significant. However, before this finding is used to derive different cut-off values for health screening, we would argue that the relationships between waist circumference and risk factors at different ages need to be further examined.

Table 4.4.1. Characteristics of 20 women in the magnetic resonance imaging study.

	Mean	SD	Range
Age (years)	34.4	10.0	20.0-51.1
Weight (kg)	66.8	14.0	46.0-96.1
Height (cm)	162.3	6.5	148.4-171.9
Body mass index (kg/m^2)	25.2	4.5	19.6-33.0
Waist circumference (cm)	78.6	10.7	61.6-97.3
Waist sagittal diameter (cm)	20.5	3.6	15.5-27.0
Waist transverse diameter (cm)	27.7	3.0	23.1-33.0
Waist to hip ratio	0.78	0.07	0.67-0.89
Subcutaneous skinfolds (mm)*	67.4	27.2	30.3-122.5
Intra-abdominal fat volume (kg)	0.96	0.77	0.07-2.66

*Sum of skinfolds measured at biceps, triceps, subscapular and supra-iliac sites.

Table 4.4.2. Correlation coefficients between intra-abdominal fat areas (measured by magnetic resonance imaging) at different levels between the xiphisternum and anterior iliac crest and different indices of adiposity in 20 women, using linear regression analysis.

	Intra-abdominal fat areas				
	Xiphisternum	1/3 distance from xiphisternum to anterior iliac crest	2/3 distance from xiphisternum to anterior iliac crest	Anterior iliac crest†	Intra-abdominal fat volume
Waist circumference	0.890***	0.908***	0.870***	0.773***	0.889***
Waist to height ratio	0.865***	0.879***	0.828***	0.696**	0.844***
Waist sagittal diameter	0.881***	0.892***	0.850***	0.770**	0.876***
Waist transverse diamter	0.867***	0.887***	0.859***	0.781***	0.877***
Waist to hip ratio	0.523*	0.567**	0.600**	0.502*	0.569**
Body mass index	0.886***	0.887***	0.812***	0.704***	0.848***
Subcutaneous skinfolds*	0.739***	0.749***	0.722***	0.673**	0.744***
Intra-abdominal fat volume	0.962***	0.980***	0.991***	0.938***	—

***P <0.001, P <0.01, *P <0.05; *sum of skinfolds measured at biceps, triceps, subscapular and supra-iliac sites. †the level of anterior iliac crest approximately correspond to commonly used L4-L5 computerised tomography slice.

Table 4.4.3. Proportions of the variance of intra-abdominal fat volume (measured by magnetic resonance imaging) and indices of adiposity explained by height in 20 women, using linear regression analysis.

	Adjusted r^2	P
Intra-abdominal fat volume	0.013	0.394
Waist circumference	0.004	0.312
Waist sagittal diameter	0.005	0.354
Waist transverse diameter	0.006	0.201
Waist to hip ratio	0.002	0.339
Body mass index	0.020	0.334
Subcutaneous skinfolds*	0.010	0.522

*Sum of skinfolds measured at biceps, triceps, subscapular and supra-iliac sites.

Table 4.4.4. Variances of intra-abdominal fat volume (measured by magnetic resonance imaging) explained by waist to height ratios of different levels of index power for height in 20 women, using linear regression analysis.

	Waist to height^p ratios of different levels of index power						
	-0.50	-0.25	0.00†	0.25	0.50	0.75	1.00‡
Adjusted r^2 (%)	77.0***	77.8***	77.8***	77.1***	75.4***	72.9***	69.6***

***P <0.001; †waist to height^0 = waist circumference alone; ‡waist to height^1 = waist to height ratio.

Table 4.4.5. Characteristics of 71 men and 34 women in the computerised tomography study.

	Men ($n = 71$)			Women ($n = 34$)		
	Mean	SD	Range	Mean	SD	Range
Age (years)	52.0	17.2	19.4-84.7	52.6	13.3	19.4-72.1
Weight (kg)	73.5	11.3	54.0-102.0	69.6	12.3	50.0-103.0
Height (cm)	177.6	8.5	158.4-197.0	164.2	6.3	151.3-182.0
Body mass index (kg/m^2)	23.4	3.1	17.8-31.6	26.0	5.0	19.4-38.3
Waist circumference (cm)	90.9	9.5	71.4-111.5	94.6	14.7	74.0-125.4
Waist to hip ratio	0.96	0.05	0.08-1.10	0.94	0.08	0.79-1.09
Subcutaneous skinfolds (mm)*	32.4	15.6	9.5-80.0	50.2	22.0	13.2-87.5
Intra-abdominal fat area (cm^2)	89.9	53.0	12.7-274.0	91.8	52.7	18.8-221.0

*Sum of skinfolds measured at abdomen and supra-iliac sites.

Table 4.4.6. Proportions of variance and t values of intra-abdominal fat area measured by computerised tomography and anthropometric indices explained by age and height in 71 men and 34 women, using multiple linear regression analysis.

	Men (n = 71)			Women (n = 34)		
	Predictor: Age					
	υ_A	t_A	P_A	υ_A	t_A	P_A
Intra-abdominal fat area	0.141	3.540	<0.001	0.272	3.748	<0.001
Waist circumference	-0.001	0.978	0.332	0.262	3.663	<0.001
Waist to hip ratio	-0.007	0.721	0.473	0.093	2.089	0.045
Body mass index	-0.013	0.235	0.235	0.121	2.411	0.021
Subcutaneous skinfolds*	0.043	-2.042	0.045	0.091	2.100	0.044
	Predictors: Age + Height					
	υ_{H+A}	t_H	P_H	υ_{H+A}	t_H	P_H
Intra-abdominal fat area	0.147	-1.029	0.231	0.289	-1.354	0.185
Height	0.361	-6.409	<0.001	0.038	-1.543	0.132
Waist circumference	-0.009	0.663	0.510	0.275	-1.272	0.212
Waist to hip ratio	-0.013	-0.761	0.450	0.148	-1.762	0.088
Waist to thigh ratio	0.497	0.401	0.690	0.372	-1.552	0.131
Body mass index	0.008	-1.576	0.120	0.216	-1.721	0.095
Subcutaneous skinfolds*	0.032	0.463	0.645	0.107	-1.257	0.218

υ = variance proportion (adjusted); t = t value; A = age; H = height; υ_{H+A} = total of variance proportions from height and age combined; *sum of skinfolds measured at abdomen and supra-iliac sites.

Table 4.4.7. Correlation coefficients between intra-abdominal fat area measured by computerised tomography and anthropometric indices in 71 men and 34 women, with and without age adjustment.

	Men ($n = 71$)		Women ($n = 34$)	
	Unadjusted	Age adjusted‡	Unadjusted	Age adjusted‡
Waist circumference	0.820***	0.847***	0.800***	0.719***
Waist to height ratio	0.890***	0.873***	0.795***	0.713***
Waist to hip ratio	0.748***	0.778***	0.503***	0.401***
Body mass index	0.752***	0.805***	0.806***	0.770***
Subcutaneous skinfolds†	0.550***	0.720***	0.702***	0.653***
Height	-0.008^{ns}	0.080^{ns}	-0.313^{ns}	-0.216^{ns}

***P <0.001, ns - not significant; †sum of skinfolds measured at abdomen and supra-iliac sites; ‡partial correlation analysis.

Table 4.4.8. Variances of intra-abdominal fat area (measured by computerised tomography) explained by waist circumference or waist to height ratio in 71 men and 34 women, using linear or quadratic regression analysis.

		Men ($n = 71$)		Women ($n = 34$)	
		<50 years	≥50 years	<50 years	≥50 years
		r^2 (%)	r^2 (%)	r^2 (%)	r^2 (%)
Waist circumference	Linear	75.7	71.8	49.1	58.9
	Quadratic	76.8	71.8	52.0	59.5
Waist to height ratio	Linear	76.4	77.9	53.4	58.6
	Quadratic	76.4	79.0	55.4	59.0

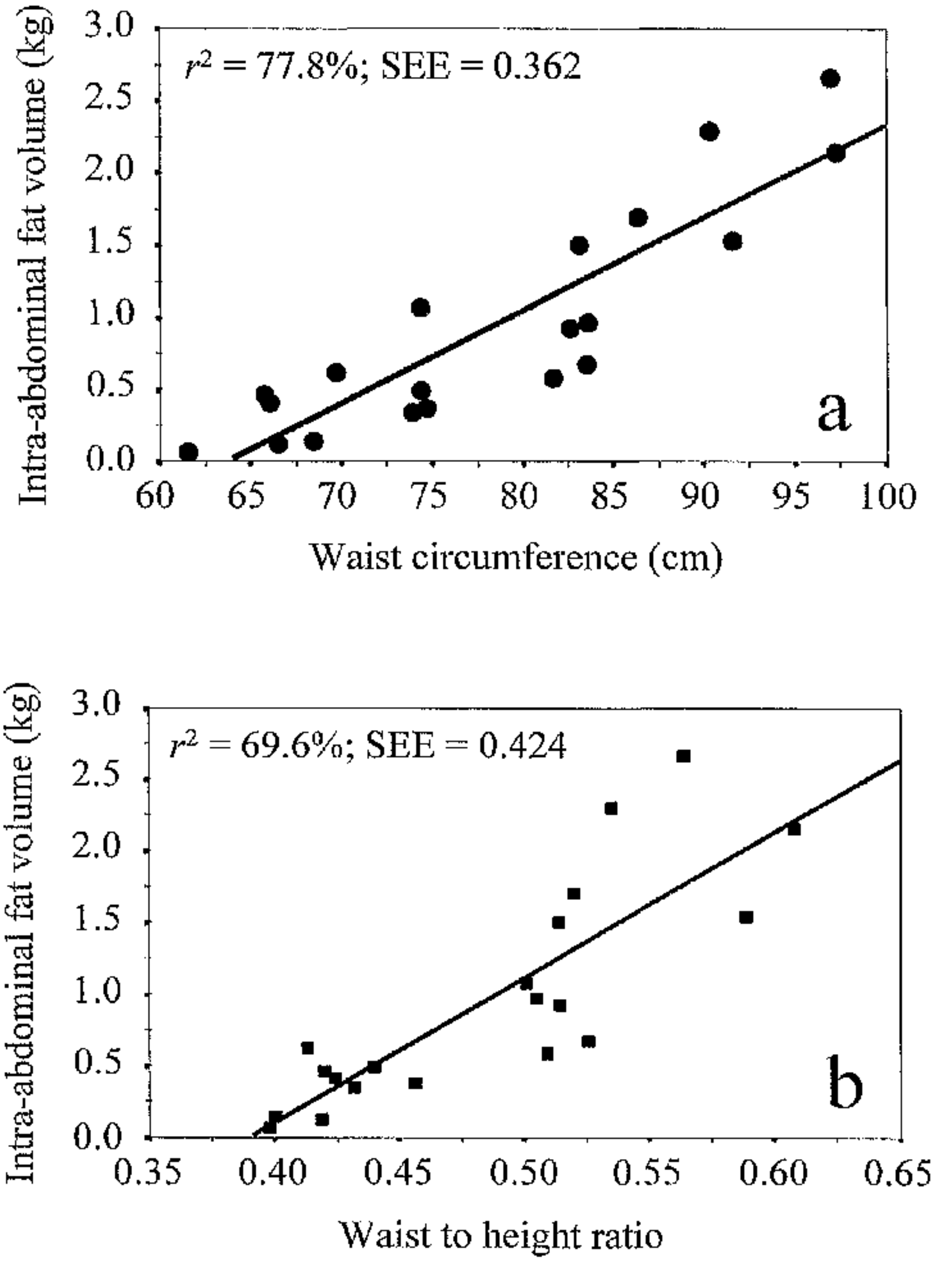


Figure 4.4.1. Plots between intra-abdominal fat volume measured by magnetic resonance imaging and waist circumference (intra-abdominal fat volume = 0.0641 × waist circumference - 4.072) (a), and waist to height ratio (intra-abdominal fat volume = 10.126 × waist to height ratio - 3.943) (b) in 20 women.

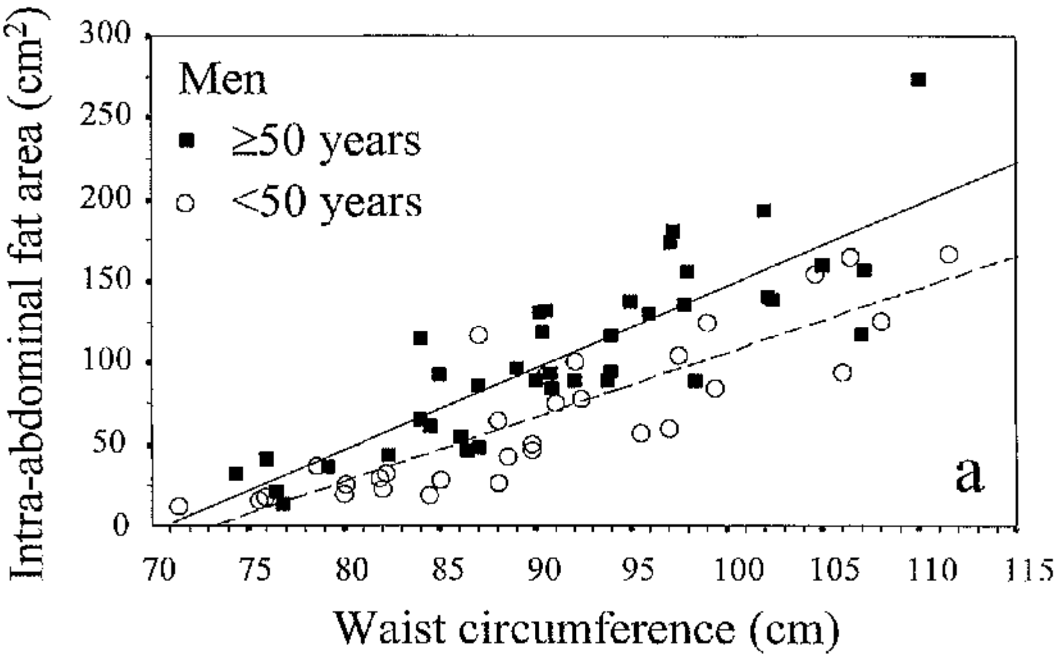


Figure 4.4.2a. Plots between intra-abdominal fat area measured by computerised tomography and waist circumference for separate age groups above and below 50 years in 71 men [<50 year age group: intra-abdominal fat area = 3.96 (95% CI: 3.11 to 4.81) × waist circumference - 288.9 (95% CI: -366.1 to -211.7); ≥50 year age group: intra-abdominal fat area = 5.04 (95% CI: 3.98 to 6.09) × waist circumference - 356.3 (95% CI: -453.1 to -259.6)]. Differences between gradients are significant (P <0.05).

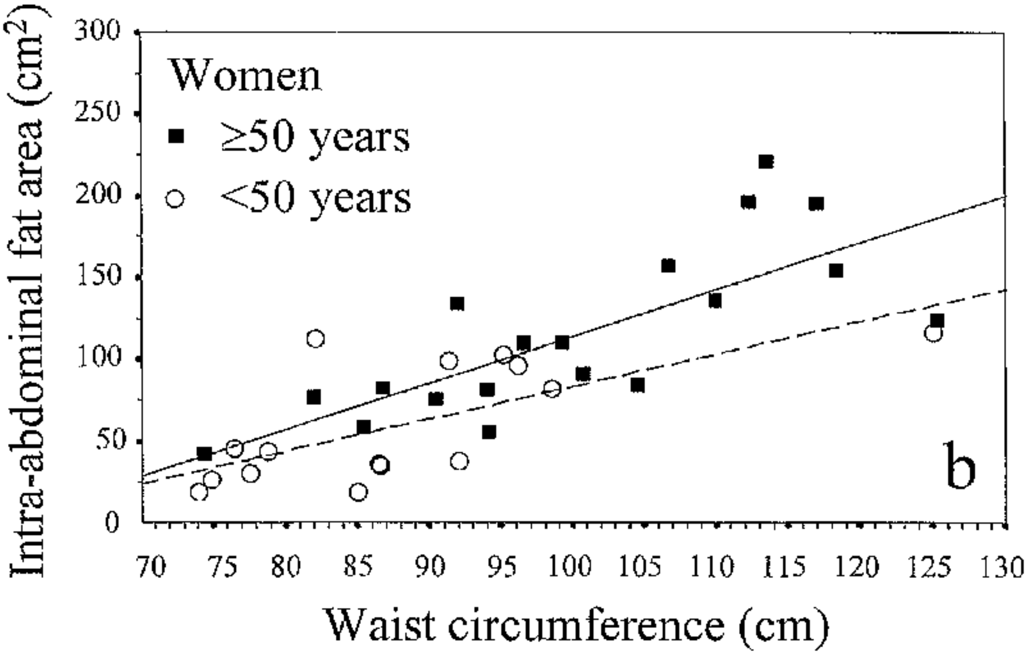


Figure 4.4.2b. Plots between intra-abdominal fat area measured by computerised tomography and waist circumference for separate age groups above and below 50 years in 34 women [<50 year age group: intra-abdominal fat area = 1.98 (95% CI: 0.82 to 3.13) × waist circumference - 114.3 (95% CI: -216.0 to -12.5); ≥50 year age group: intra-abdominal fat area = 2.85 (95% CI: 1.67 to 4.03) × waist circumference - 170.5 (95% CI: -290.0 to -51.0)]. Differences between gradients are not significant (P >0.05).

—4.5—

RELATIONSHIP BETWEEN VOLUMES AND AREAS FROM SINGLE TRANSVERSE SCANS OF INTRA-ABDOMINAL FAT MEASURED BY MAGNETIC RESONANCE IMAGING

This section has been prepared for publication as

Han TS, Kelly IE, Walsh K, Greene R, Lean MEJ. Relationship between volumes and areas from single transverse scans of intra-abdominal fat measured by magnetic resonance imaging. (in preparation).

ABSTRACT

Objective: To determine the level of a single transverse scan of intra-abdominal fat between L1 to L5 that best predicts intra-abdominal fat volumes.

Subjects: Sixteen male and seven female patients with non-insulin-dependent diabetes mellitus, aged 44-74 years.

Outcome measures: Volumes and areas from single scans of intra-abdominal fat measured by magnetic resonance imaging with a 1.5 Tesla magnetic field.

Results: Intra-abdominal fat volumes calculated from fat areas between 8 to 9 cross-sectional transverse single scans of 20 mm thickness. Men and women, respectively, had mean body mass index of 27.9 (SD 3.0) and 31.6 (SD 4.7) kg/m^2, and intra-abdominal fat volumes 2.3 (SD 0.5) and 2.5 (SD 0.6) kg. Intra-abdominal fat area of the fourth scan (in the direction of L1 to L5) gave the highest prediction of total intra-abdominal fat volumes both in men (r = 0.959, P <0.001) and in women (r = 0.973, P <0.001). The intra-abdominal fat area of the third scan gave an almost as good prediction. These third and fourth levels of scans corresponded to L2 and L3 vertebrae in most subjects. The intra-abdominal fat areas scanned from the sixth and seventh level, corresponded to the frequently used L4-L5, had lower correlations with intra-abdominal fat volumes. There were no sex differences in the prediction of volumes from areas of intra-abdominal fat. Intra-abdominal fat areas from the fourth scan explained 93% of variance (SEE = 0.14 kg) of total intra-abdominal fat volumes.

Conclusions: In large studies of intra-abdominal fat using magnetic resonance imaging, a single intra-abdominal fat area at the levels between L2 and L3 vertebrae, i.e. close to the level for measuring waist circumference as defined by the World Health Organisation (1995), offers a cheaper and faster method, with high prediction of total intra-abdominal fat volumes.

Keywords: fat distribution, health promotion, methodology, obesity, visceral fat.

INTRODUCTION

Increased accumulation of the metabolically active intra-abdominal fat (Kissebah *et al*, 1982) is thought to be responsible for a variety of metabolic disorders (Björntorp, 1990). This topic has been reviewed in detail in **Chapter 1**. Measuring total abdominal fat using magnetic resonance imaging (MRI) requires a series of consecutive images in order to calculate the volume. Measuring total volume in studies of large numbers of subjects is not practical due to time consuming and high costs. Our previous MRI study of twenty women has shown that a single cut at 2/3 the distance between xiphisternum and anterior iliac crest, approximately at the L2-L3 level in most subjects gave the highest correlation with intra-abdominal fat volume (**Chapter 4.4, Table 4.4.2**). This section, describes the methods for measuring extra- and intra-abdominal fat volumes using multiple MRI scans, and determines the level of a single transverse scan of intra-abdominal fat between L1 to L5 that best predicts intra-abdominal fat volumes.

METHODS

Subjects

Sixteen men and seven women with non-insulin-dependent diabetes mellitus took part in a randomised, double blind twelve week follow up study of the effects of troglitazone (a thiazolidinedione compound which enhances the effects of insulin in peripheral tissues and the liver) on intra-abdominal fat mass. Subjects underwent comprehensive physiological assessments as well as body composition measurements using a variety of standard techniques including underwater weighing, anthropometry and MRI (Kelly *et al*, 1997). This section presents only the analysis of baseline MRI data.

Magnetic resonance imaging

The tissues of the abdomen were scanned using MRI machine (Siemens, Germany) (see **Figure 1.2.5**, page 15 of **Chapter 1**) with a magnetic field strength of 1.5 Tesla. Ordinary spin echo sequences was used with repetition time (TR) of 350 ms and echo time (TE) of 12 ms for the abdomen measurement.

Abdominal fat measurement

Calibrations of lipid and water

A lump of lard (lipid) was placed next to a container of water in the MRI scanner to simulate lipid in adipose tissue (AT) and lean tissue *in vivo*. The scan was analysed to obtain the threshold value where only the fat in the lard could be imaged (whilst the imaging of water just disappears). Pilot tests determined the threshold value to be at 300 (arbitrary units) for every subject for subsequent calculations.

Abdominal fat imaging

Four sagittal images of the trunk were scanned to find the vertebral column. To obtain reproducible imaging volumes, the volume of the abdomen was taken to extend from the bottom of the inferior plate of the L1 vertebra to the bottom of inferior plate of the L5 (**Figure 4.5.1a**). Data were collected from as many 20 mm thick sections (**Figure 4.5.1b**) as could completely fit within that interval. This imaging volume approximately corresponds to the levels from xiphisternum to anterior iliac crest in our previous MRI studies (Han *et al*, 1997b, see **Chapter 4.4**), but was more reproducible.

Calculations of intra-abdominal and extra-abdominal adipose tissue and fat volumes

After setting an appropriate threshold value (300 window level) that separates fat (lipid) from lean tissues (water), the volume of intra-abdominal and extra-abdominal AT were calculated. The number of pixels for total abdominal AT was obtained from the region of interest by encircling the whole abdomen contents with an ovoid line (**Figure 4.5.1c**). To obtain the number of pixels for intra-abdominal AT, the ovoid line was then reduced to encircle the intra-abdominal contents at the position of the fascial plane to separate intra-abdominal from extra-abdominal AT (**Figure 4.5.1d**). Total volume of abdominal AT (mm^3) was obtained by summing the AT areas in eight (or nine in eight men) transverse scans obtained in each subject, and multiplied by 20 mm (slice thickness). A factor of 10^{-6} was used to convert mm^3 to litre of AT volume, and then to volume of fat (kg) assuming AT contains 80% of fat, 2% protein, 18% of water with negligible minerals (Garrow, 1974), with corresponding densities of 0.900, 1.34 and 0.993 kg/l

(Siri, 1961), giving an average AT density of 0.9255 kg/l. Thus fat was converted from AT by a factor of 0.9255 × 80%. The difference between the total volumes of abdominal fat and intra-abdominal fat provides the total volume of extra-abdominal fat.

Statistical analysis

Relationships between volumes and single areas of intra-abdominal fat were determined using linear regression analysis in each sex separately, and partial correlation in both sexes together, to control for sex.

RESULTS

Table 4.5.1 shows the characteristics of sixteen men and seven women. Most subjects were overweight with large intra-abdominal fat deposition, as expected in patients with non-insulin-dependent diabetes mellitus.

Table 4.5.2 shows the correlations between single intra-abdominal fat areas scanned at 20 mm intervals between the L1 and L5 vertebrae. Eight cross-sectional images of intra-abdominal fat areas between L1 and L5 were obtained in most subjects, and nine images in eight men with longer trunk. All single areas correlated highly with total volumes of intra-abdominal fat. Intra-abdominal fat areas in the fourth (in the direction of L1 to L5) gave the best correlation with the volumes both in men (r = 0.959, P <0.001) and in women (r = 0.973, P <0.001). Correlations between these two variables remained highest when men and women were analysed together, with or without adjustment for sex. **Figure 4.5.2** shows the close relationship between total intra-abdominal fat volumes and intra-abdominal fat areas taken at the fourth scan. **Table 4.5.3** shows the regression equations to predict volumes from areas of intra-abdominal fat separately for men and women and for both sexes combined. The areas from the fourth scan explained 93% of variance (SEE = 1.4 kg) of the volumes of intra-abdominal fat in men and women together. Adjusting for sex in multiple linear regression analysis did not improve the prediction and sex was not a significant factor (data not presented). The gradients and intercepts of the regression lines were not significantly different between the two sexes. Intra-abdominal fat areas from the third scan also correlated well with the total volumes. The third and fourth scanning levels in the present study corresponded approximately to the L2 and L3 vertebrae in most subjects. Intra-abdominal fat areas from the sixth and seventh levels corresponded to that from the frequently used L4-L5 level for a single image, had lower correlations with intra-abdominal fat volumes.

DISCUSSION

In the present study, after a pilot study, a single threshold (300) was set for all subjects to distinguish fat tissue from other tissues. Because intra-abdominal fat locates within an almost circular perimeter of fascial plane (**Figure 4.5.1c-d**), an ovoid was used to encircle this region of interest for calculations. The coefficient of variation using this method for repeated calculations (Bland, 1987) was less than one percent, which improved on the previous 'hand drawn' method in the earlier MRI study (**Chapter 4.4**).

Measuring total intra-abdominal fat volume is time consuming, requiring many scans, which adds on to the high costs. The present study has shown that both in men and in women, the intra-abdominal fat areas in the third and fourth scans (in the direction of L1 to L5), which approximately correspond to the levels of L2 and L3 vertebrae, gave the highest prediction of intra-abdominal fat volumes. Single intra-abdominal fat areas from levels 6 and 7, which correspond to the frequently used L4-L5 level in scanning technique (Lemieux *et al*, 1996b), had lower correlations with the volumes. These findings are supported by our previous MRI study of women and the very recent publication of Abate *et al* (1997), suggesting that a single scan at L2-L3 is valid for estimating total intra-abdominal fat volumes.

CONCLUSIONS

The present study employed a novel method for intra-abdominal fat calculations. Intra-abdominal fat area from a single transverse cross-sectional scan at approximately L2-L3, is a valid estimate of total intra-abdominal fat volume, which could be used in studies of large number of subjects to save time and costs.

Table 4.5.1. Characteristics of 16 men and 7 women.

	Men (n = 16)			Women (n = 7)		
	Mean	SD	Range	Mean	SD	Range
Age (years)	56.2	6.3	44.1-65.7	62.3	9.1	49.1-74.1
Weight (kg)	81.1	11.7	61.7-107.2	77.6	11.5	61.8-94.0
Height (cm)	171.0	6.8	159.0-183.0	156.9	4.2	149.0-162.0
Body mass index (kg/m^2)	27.9	3.0	22.9-34.1	31.6	4.7	24.6-37.1
Waist circumference (cm)	100.3	9.9	82.1-122.5	107.1	9.0	96.2-120.6
Intra-abdominal fat area from L1 to L5 vertebra (cm^2)						
Level 1	232.2	47.5	145.3-308.2	205.2	59.5	110.9-275.8
Level 2	199.7	51.5	108.9-287.2	178.5	66.6	77.0-261.7
Level 3†	210.2	53.3	124.0-291.7	209.9	62.2	100.6-278.7
Level 4†	194.3	41.3	135.3-245.0	208.9	57.9	136.1-298.3
Level 5	200.4	51.7	135.1-299.4	232.4	63.6	155.1-322.2
Level 6‡	175.5	43.2	116.1-245.9	218.2	57.5	137.6-300.7
Level 7‡	158.2	35.2	106.4-203.9	219.2	52.4	156.7-287.4
Level 8	139.1	29.8	83.8-187.3	226.4	47.8	155.2-295.2
Level 9§	140.8	28.8	95.9-179.1	—	—	—
Total fat volume from L1 to L5 vertebra (kg)¶						
Abdominal fat	3.90	0.52	3.14-4.85	6.04	1.15	4.42-7.53
Intra-abdominal fat	2.34	0.47	1.71-2.99	2.52	0.63	1.64-4.64
Extra-abdominal fat	1.56	0.09	1.00-2.06	3.53	0.67	2.70-4.36

†Correspond to the levels of L2 and L3 vertebrae, i.e. close to the level for measuring waist circumference as defined by the World Health Organisation (1995); ‡correspond to the levels of L4 and L5 vertebrae; §nine transverse scans were fitted in between L1 and L5 in eight men; ¶see methods section for calculations of total abdominal fat volumes from cross sectional transverse abdominal fat areas.

Table 4.5.2. Correlation coefficients between total intra-abdominal fat volumes and intra-abdominal fat areas from single transverse scans of at different levels between L1 to L5 vertebrae, measured by magnetic resonance imaging in 16 men and 7 women.

	Men	Women	Both sexes together	
			Unadjusted	Sex adjusted†
Scan level				
Level 1	0.864***	0.802***	0.763***	0.839***
Level 2	0.840***	0.846***	0.789***	0.842***
Level 3‡	0.921***	0.958***	0.921***	0.933***
Level 4‡	0.959***	0.973***	0.966***	0.965***
Level 5	0.883***	0.957***	0.910***	0.912***
Level 6§	0.909***	0.949***	0.902***	0.925***
Level 7§	0.913***	0.881***	0.813***	0.897***
Level 8	0.864***	0.872***	0.675***	0.864***
Level 9¶	0.912***	—	0.912***	—

†Partial correlations; ‡correspond to the levels of L2 and L3 vertebrae; §correspond to the levels of L4 and L5 vertebrae; ¶nine transverse scans were fitted in between L1 and L5 in eight men.

Table 4.5.3. Regression equations to predict intra-abdominal fat volume from intra-abdominal fat area separately and together for men and women.

Dependent variable: Intra-abdominal fat volume (kg)	Independent variable: Intra-abdominal fat area (cm^2)					
	Gradient (×10)		Intercept		r^2	SEE
	β	95% CI	β	95% CI	(%)	(kg)
Men†	0.110***	0.091, 0.129	0.204^{ns}	-0.165, 0.572	91.4	0.139
Women†	0.105***	0.077, 0.134	0.316^{ns}	-0.303, 0.934	93.6	0.158
Both sexes	0.108***	0.095, 0.121	0.244^{ns}	-0.026, 0.513	92.9	0.138

†No differences in gradients or intercepts between men and women, P >0.05; ***P <0.001, ns = not significant.

Figure 4.5.1. Abdominal fat images from magnetic resonance imaging (MRI).

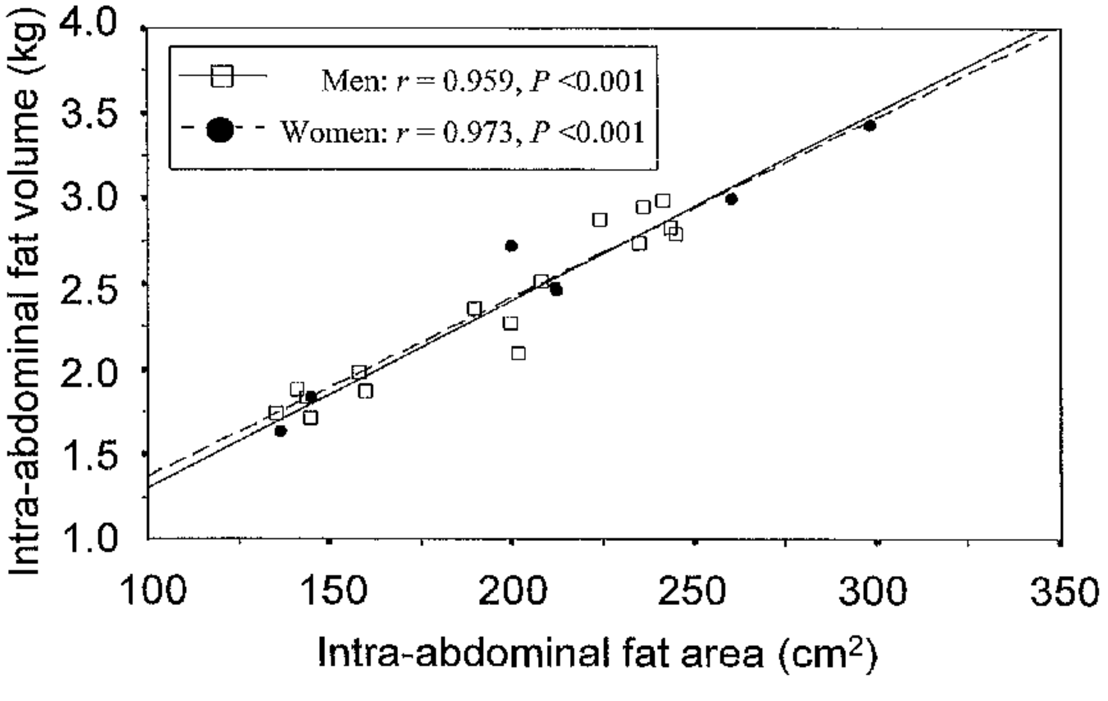


Figure 4.5.2. Relationship between total volumes and single transverse cross-sectional areas of intra-abdominal fat scanned at the fourth level of the distance from L1 to L5 vertebra, measured by magnetic resonance imaging, in 16 men and 7 women. Regression equation for both sexes (adjusted variance = 92.9%, SEE = 0.138 kg): **Intra-abdominal fat volume** (kg) = 0.1082 (95% CI: 0.0949 to 0.1214, P <0.001) × 10 × **Intra-abdominal fat area** (cm^2) + 0.2436 (95% CI: -0.0262 to 0.5134, P = 0.074).

|| CHAPTER FIVE

EPIDEMIOLOGY OF BODY MORPHOLOGY AND ASSOCIATED ILL HEALTH IN A CROSS-SECTIONAL POPULATION SURVEY

|| CONTENTS OF CHAPTER FIVE — PAGES

— 5.1 —

ASSOCIATIONS BETWEEN BODY FAT DISTRIBUTION AND LIFESTYLE FACTORS

This section has been submitted for publication as

<u>Han TS</u>, Bijnen FCH, Lean MEJ, Seidell JC. Separate associations of waist and hip circumference with lifestyle factors. (submitted).

Collaboration with MORGEN project

ABSTRACT

Objective: To study the associations of lifestyle factors with waist circumference, hip circumference, and body mass index.

Design: Cross-sectional study in a random sample of 5887 men and 7018 women aged 20-59 years, selected from the civil registries of Amsterdam, Maastricht and Doetinchem, in the Netherlands.

Results: Results were compared to those in reference groups: non-smokers, occasional drinkers, highest educated, physically active, employed subjects, women who had no live births, or 20-29 year-olds. In multivariate logistic regression analysis, odds ratios (95% confidence interval) for those with a waist above the previously defined Action Level 2 (≥94 cm in men, ≥88 cm in women) were significantly lower in smokers, and higher in heavy drinkers, inactive subjects, unemployed persons, those educated below secondary level, women who had ≥3 live births, and older age. Mean waist to hip ratio adjusted for body mass index and age were higher in these subjects. Residual analysis showed that the risk of having larger waist than expected from their body mass index were 1.2 times (1.1 to 1.4) in male smokers, 1.4 times (1.2 to 1.7) in male and 1.7 times (1.3 to 2.2) in female heavy drinkers, 1.6 times (1.5 to 1.8) in inactive men, and 1.3 times (1.1 to 1.5) in unemployed women. The risk of having smaller hips than expected from body mass index were 1.2 times (1.1 to 1.4) in male and 1.2 times (1.0 to 1.3) in female smokers, 1.2 times (1.1 to 1.3) in men and 1.1 times (1.0 to 1.2) in women who were inactive.

Conclusions: Each lifestyle factor may influence the size of waist and the hips differently, and understanding these influences is important for health promotion directed at general public.

Keywords: Body shape, drinking, health promotion, physical activity, smoking.

INTRODUCTION

When waist circumference approaches Action Level 1 (94 cm in men, 80 cm in women), subjects should be aware of the increased health risks. In the 'Alert Zone' between Action Level 1 and Action Level 2 (94-102 cm in men, 80-88 cm in women), people should not further gain weight, most should modify lifestyle such as increasing physical activity level, and some would benefit from self managed weight loss. Above this range, in the 'Action Zone' (≥102 cm in men, ≥88 cm in women), every body should be urged to take action to seek professional help to achieve sustained weight loss and for risk factor screening (**Chapter 4.2**; Han *et al*, 1996c).

Associated with overweight, indicated by high body mass index, and adverse body fat distribution, indicated by high waist to hip ratio or large waist circumference, are clusters of symptoms and associated secondary chronic diseases, which are confounded by smoking (Shimokata *et al*, 1989; Lissner *et al*, 1992; Troisi *et al*, 1991), physical inactivity (Troisi *et al*, 1991), parity (den Tonkelaar *et al*, 1990), and low educational level (Seidell *et al*, 1986a). The relationship between alcohol consumption and body fatness is still unclear (Prentice, 1995). Published relationships between lifestyle factors and body fat distribution are difficult to interpret because they involve the waist to hip ratio, which could be related to either or both the waist and hip circumferences. Waist to hip ratio is related to both increased visceral fat and reduced leg muscle areas in men (Seidell *et al*, 1989a). Higher frequency of impaired glucose tolerance in Indian compared to Swedish men has been shown to relate to the ratio of lower leg muscle to total body muscle, not to excess visceral fat (Chowdhury *et al*, 1996). Patients with Cushing's syndrome have both increased visceral fat and peripheral muscle wastage (Rebuffé-Scrive *et al*, 1988). High waist to hip ratio in alcoholic men is related to reduced gluteal muscle (Kvist *et al*, 1993). Dissociating the relative contributions of the two measures in waist to hip ratio in the associations with lifestyle factors may have important implications in terms of the interpretations of the associations between metabolic complications and the distribution of body 'fat' or 'muscle'.

The present study addressed two main issues: firstly, to highlight the associations of measures of overweight and abdominal fat distribution, with the main focus on the waist circumference Action Levels, with age and lifestyle factors, and secondly, to elucidate the associations of the lifestyle factors with waist and hip circumferences.

METHODS

Subjects

Men (n = 5887) and women (n = 7018) aged 20-59, recruited into the ongoing MORGEN (Monitoring of Risk Factors and Health in The Netherlands) study in the 1993 to 1995 cohorts.

Anthropometry and lifestyle factors

All anthropometric measurements were made according to the World Health Organisation (1989) recommendations by paramedical personnel. Subjects wore light clothes during measurements of body weight to the nearest 100g using calibrated scales, height in bare feet to the nearest mm, waist circumference in duplicate at the level between the lowest rib margin and iliac crest, and hip circumference at the widest trochanters to the nearest mm, the mean values of circumferences were used in analysis. Waist to hip circumferential ratio was computed, and body mass index was calculated as weight (kg) divided by height squared (m^2). Lifestyle factors were obtained from a questionnaire.

Statistical analysis

1. Associations between lifestyle factors with adiposity

The prevalence of overweight and adverse fat distribution in each lifestyle group were determined by cross tabulation. Independent dummy variables were created for age and lifestyle factors (**Appendix 5.1.1**).

Logistic regression analysis used fat distribution and overweight, dichotomised at pre-selected cut-off based on published criteria, as dependent variables. Waist circumference was dichotomised at Action Level 2 (102 cm in men and 88 cm in women) (**Chapter 4.1**; Lean *et al*, 1995), body mass index at 30 kg/m^2 (WHO, 1989), and waist to hip ratio at 0.95 in men and 0.80 in women (US Department of Agriculture and US Department of Health and Human Services, 1990). Linear regression analysis using least squares means to adjust body mass index and age for obtaining the mean values of waist to hip ratio, in different lifestyle groups.

2. *Residuals analysis to determine the relative contributions of waist and hip circumferences in their associations with lifestyle factors*

Linear regression analysis using body mass index as independent predictor of waist or hip circumference was used to determine their respective residuals with and without age adjustment. **Figure 5.1.1** illustrates the relationship between waist circumference and body mass index. The residuals obtained (measured circumference minus circumference predicted from their body mass index) were dichotomised to create dependent variables, the lower (negative residuals) waist than expected group and the higher (positive residuals) hips than expected group were used as reference groups (value of 0) for higher waist than expected and lower hips than expected (value of 1) respectively.

RESULTS

1. *Associations of waist circumference* Action Level *2, body mass index and waist to hip ratio with age and lifestyle factors*

Subject characteristics are shown in **Table 5.1.1**. Compared to the reference groups: 20-29 years, non-smokers, occasional alcohol drinkers, physically active subjects, most educated subjects, those currently employed, and women who never had a live birth (**Appendix 5.1.1**), **Tables 5.1.2a & b** show that heavy drinkers and non-drinkers (women only), inactive subjects, those with lower education (below educational level 2), unemployed subjects, housewives, and women who had given to 3 or more live births, were more likely to associate with waist circumference above Action Level 2. Smokers were associated with small waist circumference.

Lifestyle factors related to body mass index similarly to waist circumference (for clarity, results not presented), but there were some differences in there relationships with waist to hip ratio. The odds ratios for those with waist to hip ratio ≥0.95 in men and ≥0.80 in women were not significantly different between smokers and non-smokers. Compared to their respective reference groups (**Appendix 5.1.1**), odds ratios for high waist to hip ratio (≥0.95 in men, ≥0.80 in women) (US Department of Agriculture and US department of Health and Human Services, 1990) were significantly higher in older subjects, heavy drinkers, inactive subjects, the least educated, unemployed subjects (women only) and housewives, and women who had given to live births (data not presented). **Figures 5.1.2a & b** show the mean values of waist to hip ratio for selected lifestyle factors, with adjustments for body mass index and age. Compared to the reference groups (**Appendix 5.1.1**), mean values of waist to hip ratio were higher in smokers, physically inactive subjects, heavy drinkers and unemployed women. Older age, lower educated subjects, women who had given to live birth, and housewives were also significantly associated with high waist to hip ratio (results not shown).

2. *Residuals analysis to determine the influences of lifestyle factors on expected waist and expected hips for a given body mass index*

Compared to their reference groups (**Appendix 5.1.1**), **Tables 5.1.3a & b** show that those with waist circumference larger than expected for their body mass index were significantly associated with increasing age, smoking in the past and present (men only), heavy alcohol consumption, inactivity (men only), lower education, unemployment and high parity (women only). Hip circumference smaller than expected was significantly associated with increasing age, smoking in the past (men only) and in the present, inactivity, lower education, and high parity in women. Early retired subjects were less likely to have waist larger (men only) or hips smaller than expected.

DISCUSSION

Some of the associations described in the present paper have been found for individual lifestyle factors in other studies (Seidell, 1991). We have, however, been able to conduct a systematic epidemiological analysis for lifestyle effects on waist circumference, referring to the previously defined Action Level 2 (**Chapter 4.1**; Lean *et al*, 1995), body mass index at 30 kg/m^2 (WHO, 1989), and waist to hip ratio (0.95 in men, 0.80 in women) (US Department of Agriculture and US department of Health and Human Services, 1990), and explored the appropriate adjustments for confounders. The results also provide valuable information for health promotion aiming to prevent adiposity and its consequences. We have also examined the associations between lifestyle factors and waist circumference defined at Action Level 1 (94 cm in men, 88 cm in women) or body mass index at 25, and found similar trends to the associations with higher cut-offs, but with lower odds ratios (data not presented).

Aging, which is not modifiable, was the most important determinant for large waist circumference. Lifestyle factor relations to waist circumference were very similar to those for body mass index. This is because the two measures correlate very strongly (r >0.85). Waist to hip ratio showed more disparities from these two indices in the associations with lifestyle factors. Relationships with a ratio are difficult to interpret. The present study used residual analysis to describe the relative associations of waist and hip circumferences with lifestyle factors, and to identify possible effects of certain lifestyle factors on specific part of the body.

Although waist and hip circumferences correlated highly with body mass index (r >0.8), there are mean residuals of ±4 cm in waist and ±3 cm in hips (**Tables 5.1.3a** & **b**). A measured waist circumference larger than expected may indicate excess abdominal subcutaneous fat or visceral fat accumulation, whereas a hip circumference less than expected may reflect reduced femoral fat, small pelvic bone structure or gluteo-femoral muscle atrophy. Previous studies largely referred the waist to hip ratio as an indicator of fat distribution. In cross-sectional studies, residuals analysis provides a relatively simple method to dissociate individual associations of waist and hips circumferences. For example, both heavy drinkers (**Figures 5.1.2a & b**) and those in the lowest educational level (data not shown) had a high waist to hip ratio, but residuals analysis revealed that heavy drinkers had waist larger than expected, whereas those in the lowest educational level had hips lower than expected for a given body mass index (**Tables 5.1.3a & b**). Whereas male smokers appeared to have normal waist to hip ratio, they were shown to have larger waist and smaller hips than expected.

In both sexes, smokers had lower body mass indices than non smokers, agreeing with previous findings (Shimokata *et al*, 1989; Lissner *et al*, 1992), and also smaller waist circumferences, but their waist was larger (not significant in women) and hips were smaller than expected for their body mass index. A three year longitudinal study has shown that smokers gained waist more and hips less than predicted from gain in body mass, thus a gain in waist to hip ratio was observed findings (Shimokata *et al*, 1989). Lissner *et al* (1992) found women who continued to smoke gained significantly more waist to hip ratio than those who stopped smoking. In the present study, male ex-smokers had waist larger and hip circumference smaller than expected from their body mass index, but less so than smokers. Female ex-smokers had measured waist and hips as expected from their body mass index. Thus smoking cessation reduces the likelihood of excessive abdomen and recessive hips.

Heavy drinkers, especially men, had large waist circumferences, supporting the commonly observed 'beer belly' phenomenon. There was some evidence (not significant) for smaller hips than expected, perhaps in keeping with Kvist *et al* (1993) who found alcoholic men have reduced femoral muscle mass compared to non-drinkers. In the present study, only male heavy drinkers were associated with body mass index ≥ 25 kg/m^2, whereas female heavy drinkers had a similar body mass index to those who drank occasionally (results not shown). Previous studies even found an inverse relationship in women (Colditz *et al*, 1991). This paradoxical relationship in women has been discussed by Prentice (1995), who suggested that other lifestyle factors such as increased level of physical activity may offset the additional energy from alcohol.

Least educated men and women were twice and fours times, respectively, more likely to have a waist circumference exceeding Action Level 2 (≥102 cm in men, ≥88 cm in women) and high waist to hip ratio, than the highest educated group, but they also had high body mass indices. For both sexes waist was as predicted from body mass index, but hips were smaller than expected. Less educated subjects within and between countries are generally more overweight, and have more adverse fat distribution (Seidell *et al*, 1986a; Seidell, 1995a). Lack of knowledge or interest in healthy lifestyle, and poor eating habits associated with lower educational level may explain this phenomenon.

Subjects who were least physically active were more likely to have waist above Action Level 2, and waist larger (not significant in women) and hips smaller than expected from their body mass index. It is likely that the association between physical inactivity and high waist to hip ratio (**Figures 5.1.2a & b**) indicates both increased abdominal fat deposition and skeletal muscle atrophy. When other leisure physical activities were incorporated to sport participation to create physically active group who did both sport and other leisure activities and inactive group who did neither, it was found that inactive women were 1.5 times more likely to have waist larger than expected from their body mass index (data not shown). This analysis was not presented because the question for other leisure activities was not available in 1993 cohort. Our findings support recent health promotion message, encouraging a more physically active lifestyle (Pate *et al*, 1995; Blair *et al*, 1996a), which may prevent weight gain or lead to more favourable tissue distribution (Houmard *et al*, 1994; Kanaley *et al*, 1993) and a variety of other health benefits (Blair *et al*, 1996b; Bouchard *et al*, 1994).

Compared to those who had a job, unemployed persons had increased risk of large waist circumference. It has been shown that unemployed people more frequently seek medical consultations than those who have a job (Carr-Hill *et al*, 1996). Weight gain has been observed in those who lost their job (Eley *et al*, 1997; Morris *et al*, 1992). Housewives had higher body mass index, waist to hip ratio and waist circumference. Exposure to food may explain these associations. Women who had more children also had higher waist and waist to hip ratio, and their waist was larger and hips were smaller than expected. Women with high waist to hip ratio are less likely to conceive compared to those who had lower waist to hip ratio (Zaadstra *et al*, 1993), but den Tonkelaar *et al* (1990) have shown women with high parity were associated with increased waist to hip ratio.

CONCLUSIONS

Overweight and adverse fat distribution are associated with increasing age, unemployment, parity in women, low education, and by poor lifestyle factors, including physical inactivity, heavy alcohol consumption, and smoking. Each lifestyle factor influences the size of waist and the hips differently and understanding these influences is important for health promotion. Thus modifiable lifestyle factors such as smoking cessation, drinking less heavily, and a more physically active lifestyle should all be encouraged, leading to an overall healthier body shape.

Table 5.1.1. Characteristics of 5881 men and 7018 women.

	Men		Women	
	Mean	SD	Mean	SD
Age (years)	42.9	10.7	42.2	11.0
Weight (kg)	82.0	12.0	68.5	11.5
Height (cm)	178.4	7.3	165.7	6.7
Body mass index (kg/m^2)	25.8	3.5	25.0	4.2
Waist circumference (cm)	92.3	10.8	81.0	11.1
Hip circumference (cm)	101.8	6.6	102.2	8.4
Waist to hip ratio	0.905	0.072	0.791	0.070

Table 5.1.2a. Odds ratios waist circumference above Action Level 2 (≥102 cm) in different groups of lifestyle factors in men.

Independent variables†	*n*	Proportion‡	Odds ratio	95% confidence interval
20-29 years	909	4.4	1.00	
30-39 years	1389	11.3	2.63***	1.83, 3.80
40-49 years	1777	19.3	4.47***	3.15, 6.35
50-59 years	1812	28.6	6.42***	4.54, 9.07
χ^2		*297*		
Non smokers	1788	14.7	1.00	
Ex-smokers	1946	22.4	1.04	0.87, 1.24
Smokers	2129	16.7	0.77*	0.64, 0.93
χ^2		*41*		
Occasional drinkers	1393	18.2	1.00	
Non-drinkers	1021	15.5	0.99	0.79, 1.24
Moderate drinkers	2215	16.4	1.05	0.85, 1.30
Heavy drinkers	1258	22.6	1.45**	1.15, 1.81
χ^2		*26*		
Physically active	2858	12.1	1.00	
Physically inactive	3026	23.6	1.72***	1.48, 2.00
χ^2		*132*		
Educational level 3	1523	11.4	1.00	
Educational level 2	1733	14.1	1.48***	1.19, 1.83
Educational level 1	2631	24.4	2.08***	1.71, 2.51
χ^2		*135*		
Employed	4508	16.6	1.00	
Early retirement	432	14.6	0.99	0.73, 1.35
Unemployed	721	28.2	1.32**	1.09, 1.61
χ^2		*62*		

***P <0.001, **P <0.01, *P <0.05; †all independent variables were entered simultaneously in multivariate analysis; ‡percentage of subjects with waist circumference above Action Level 2.

Table 5.1.2b. Odds ratios waist circumference above Action Level 2 (≥88 cm) in different groups of lifestyle factors in women.

Independent variables†	n	Proportion‡	Odds ratio	95% confidence interval
20-29 years	1263	7.6	1.00	
30-39 years	1585	13.8	1.53**	1.16, 2.02
40-49 years	2150	25.1	2.90***	2.22, 3.78
50-59 years	2020	40.7	4.83***	3.70, 6.31
χ^2		*589*		
Non smokers	2526	24.2	1.00	
Ex-smokers	1860	26.7	1.11	0.95, 1.29
Smokers	2620	21.6	0.84*	0.73, 0.97
χ^2		*16*		
Occasional drinkers	3503	27.1	1.00	
Non-drinkers	1651	19.5	1.30***	1.12, 1.52
Moderate drinkers	1560	21.2	1.06	0.88, 1.28
Heavy drinkers	304	24.3	1.20	0.88, 1.64
χ^2		*43*		
Physically active	3274	17.5	1.00	
Physically inactive	3743	29.4	1.47***	1.30, 1.66
χ^2		*136*		
Educational level 3	1378	10.7	1.00	
Educational level 2	1765	14.8	1.66***	1.32, 2.08
Educational level 1	3875	2.7	2.61***	2.14, 3.19
χ^2		*379*		
Employed	3471	17.6	1.00	
Early retirement	450	14.7	1.08	0.80, 1.46
Unemployed	676	32.5	1.42***	1.16, 1.72
Housewives	2151	33.0	1.14*	0.99, 1.30
χ^2		*222*		
No live birth	2137	12.8	1.00	
1-2 live births	3172	26.1	1.16	0.97, 1.39
3 or more live births	1709	33.5	1.42***	1.17, 1.73
χ^2		*240*		

***P <0.001, **P <0.01, *P <0.05; †all independent variables were entered simultaneously in multivariate analysis; ‡percentage of subjects with waist circumference above Action Level 2.

Table 5.1.3a. Odds ratios for waist circumference larger or hip circumference smaller than expected for a given body mass index in subjects in different groups of lifestyle factors in men.

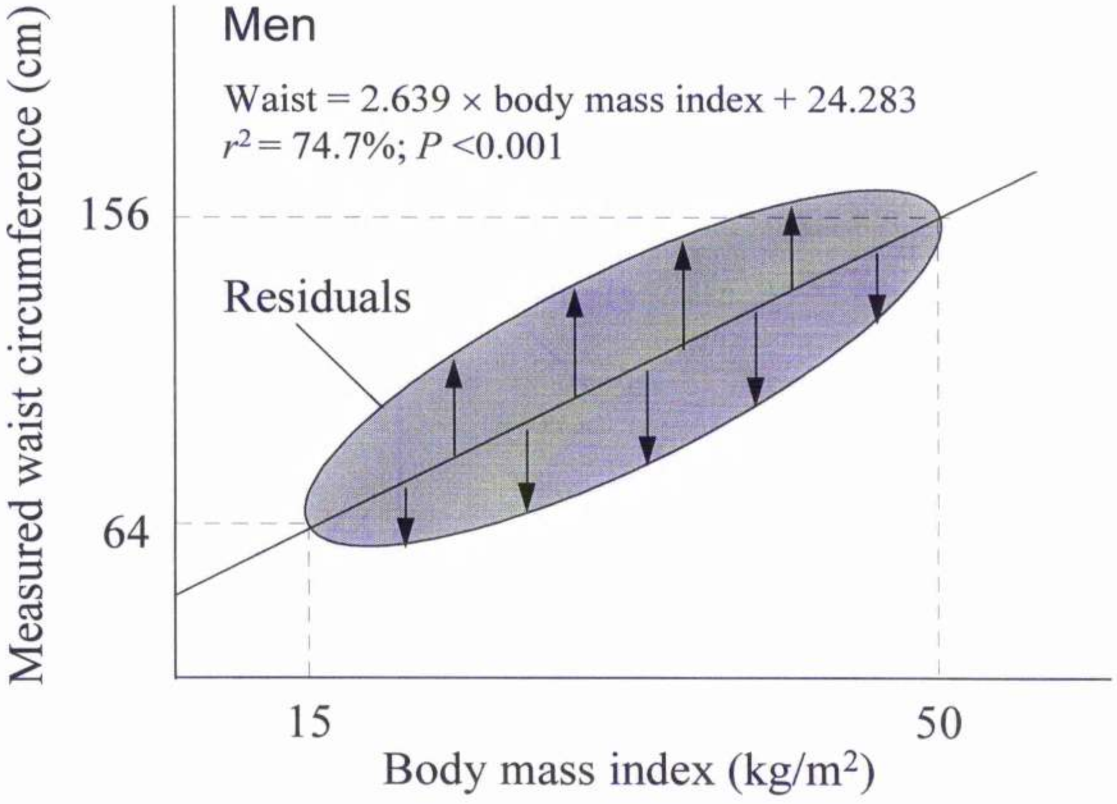
Independent variables§	Waist larger than expected† (Mean 4.28, SE 0.06 cm) Odds ratio	95% confidence interval	Hip smaller than expected‡ (Mean 3.28, SE 0.05 cm) Odds ratio	95% confidence interval
20-29 years	1.00		1.00	
30-39 years	2.10***	1.72, 2.56	1.48***	1.24, 1.78
40-49 years	3.50***	2.88, 4.26	1.92***	1.60, 2.31
50-59 years	5.72***	4.68, 6.98	2.63***	2.18, 3.18
Non smokers	1.00		1.00	
Ex-smokers	1.23*	1.03, 1.37	1.17*	1.02, 1.35
Smokers	1.23**	1.07, 1.42	1.21**	1.05, 1.39
Occasional drinkers	1.00		1.00	
Non-drinkers	0.90	0.76, 1.08	1.04	0.88, 1.24
Moderate drinkers	1.04	0.88, 1.22	1.05	0.90, 1.22
Heavy drinkers	1.40***	1.18, 1.70	1.10	0.92, 1.31
Physically active	1.00		1.00	
Physically inactive	1.64***	1.46, 1.84	1.18*	1.05, 1.32
Educational level 3	1.00		1.00	
Educational level 2	1.00	0.86, 1.16	1.44***	1.24, 1.67
Educational level 1	1.06	0.92, 1.22	1.87***	1.63, 2.15
Employed	1.00		1.00	
Early retirement	0.74**	0.59, 0.94	0.73**	0.59, 0.91
Unemployed	0.94	0.79, 1.11	1.05	0.89, 1.25

***P <0.001, **P <0.01, *P <0.05; †measured waist greater than predicted waist using BMI (predicted waist = 2.639 × BMI + 24.283; r^2 = 74.7%, P <0.001); ‡measured hip greater than predicted hip using BMI (predicted hip = 1.414 × BMI + 65.369; r^2 = 56.9, P <0.001); §all independent variables were entered simultaneously in multivariate analysis with adjustment for waist residual in hip analysis, and hip residual in waist analysis.

Table 5.1.3b. Odds ratios for waist circumference larger or hip circumference smaller than expected for a given body mass index in subjects in different groups of lifestyle factors in women.

	Waist larger than expected† (Mean 4.85, SE 0.07 cm)		Hip smaller than expected‡ (Mean 3.45, SE 0.04 cm)	
Independent variables§	Odds ratio	95% confidence interval	Odds ratio	95% confidence interval
20-29 years	1.00		1.00	
30-39 years	1.80***	1.50, 2.15	1.36***	1.14, 1.62
40-49 years	2.32***	1.93, 2.80	1.53***	1.28, 1.83
50-59 years	3.50***	2.89, 4.25	1.80***	1.49, 2.17
Non smokers	1.00		1.00	
Ex-smokers	0.99	0.87, 1.13	0.92	0.81, 1.04
Smokers	1.10	0.98, 1.24	1.15*	1.03, 1.30
Occasional drinkers	1.00		1.00	
Non-drinkers	0.99	0.87, 1.12	1.24***	1.09, 1.40
Moderate drinkers	1.14	0.98, 1.31	1.10	0.95, 1.27
Heavy drinkers	1.68***	1.29, 2.18	1.19	0.92, 1.54
Physically active	1.00		1.00	
Physically inactive	1.09	0.98, 1.21	1.10*	1.00, 1.22
Educational level 3	1.00		1.00	
Educational level 2	1.12	0.96, 1.30	1.24***	1.06, 1.44
Educational level 1	1.05	0.91, 1.22	1.56***	1.36, 1.80
Employed	1.00		1.00	
Early retirement	0.90	0.73, 1.12	0.77*	0.62, 0.95
Unemployed	1.27**	1.06, 1.51	1.17	0.98, 1.39
Housewives	1.10	0.97, 1.25	1.14	1.01, 1.29
No live birth	1.00		1.00	
1-2 live births	1.03	0.90, 1.19	1.10	0.96, 1.26
≥3 more live births	1.29**	1.10, 1.51	1.25**	1.07, 1.47

****P* <0.001, ***P* <0.01, **P* <0.05; †measured waist greater than predicted waist using BMI (predicted waist = 2.232 × BMI + 25.224; r^2 = 71.3%, P <0.001); ‡measured hip greater than predicted hip using BMI (predicted hip = 1.697 × BMI + 59.809; r^2 = 72.2%, P <0.001); §all independent variables were entered simultaneously in multivariate analysis with adjustment for waist residual in hip analysis, and hip residual in waist analysis.



Subjects with waist circumference:
↑ larger, or ↓ less than expected

Figure 5.1.1. Illustration of residuals obtained from regression between waist circumference and body mass index in men.

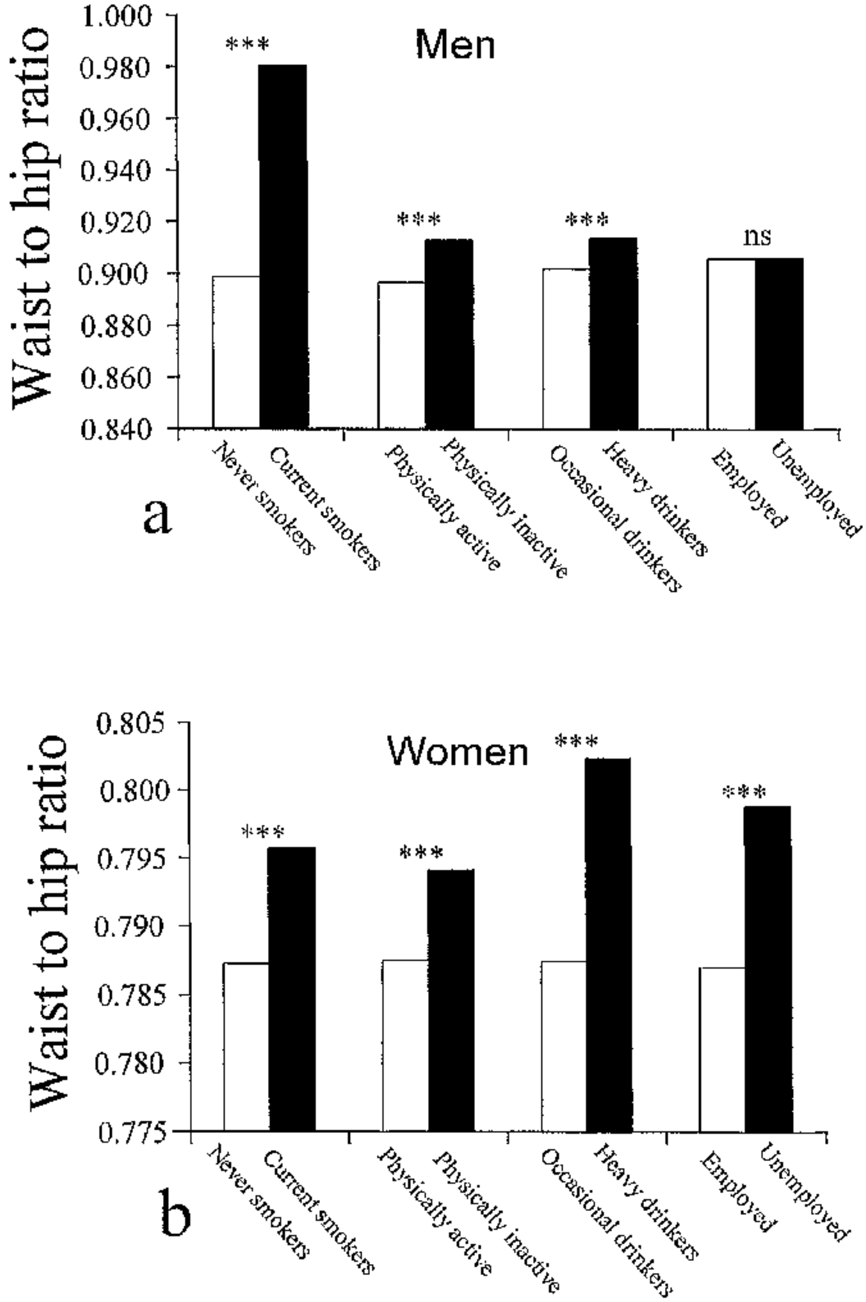


Figure 5.1.2. Mean values of waist to hip ratio with adjustments for body mass index and age in different categories of selected lifestyle factors in men (a) and in women (b).

Appendix 5.1.1. Categories of lifestyle factors as independent variables to predict waist circumference, body mass index, and waist to hip ratio.

	Reference group	Dummy variables		
		1	2	3
Age (years)	20-29	30-39	40-49	50-59
Smoking	Non-smokers	Ex-smokers	Current smokers	
Alcohol consumption (glasses/day)	Occasional (<1)	Non-drinkers (0)	Moderate (1 to <3)	Heavy (≥3)
Physical activity	Physically active (sport participation)	Physically inactive (do not do sport)		
Educational level	Level 3 (higher vocational or university)	Level 2 (vocational or higher secondary)	Level 1 (lower than secondary)	
Employment	Currently employed	Unemployed	Housewives	Early retirement
Parity (live births)	None	1-2	≥3	

WAIST CIRCUMFERENCE ACTION LEVELS IN THE IDENTIFICATION OF CARDIOVASCULAR RISK FACTORS

This section has been peer reviewed and has been published as

Han TS, van Leer EM, Seidell JC, Lean MEJ. Waist circumference Action Levels in the identification of cardiovascular risk factors: prevalence study in a random sample. *British Medical Journal* 1996; **311:**1041-45.

Collaboration with MORGEN project

ABSTRACT

Objective: To determine the frequency of cardiovascular risk factors of individuals categorised by previously defined Action Levels of waist circumference.

Design: Prevalence study in a random sample.

Setting: The Netherlands.

Subjects: 2183 men and 2698 women aged 29-59 years selected at random from the civil registry of Amsterdam, Maastricht, and Doetinchem.

Main outcome measures: Waist circumferences, waist to hip ratio, body mass index (weight (kg)/height (m^2)), total plasma cholesterol concentration, high density lipoprotein cholesterol concentration, blood pressure, age and lifestyle.

Results: A waist circumference exceeding 94 cm in men or 80 cm in women correctly classified subjects with body mass index ≥25 kg/m^2 and waist to hip ratio ≥0.95 in men and ≥0.80 in women with a sensitivity and specificity ≥96%. Men and women with at least one cardiovascular risk factor (total cholesterol ≥6.5 mmol/l, high density lipoprotein cholesterol ≤0.9 mmol/l, ≥160 mmHg systolic, ≥95 mmHg diastolic blood pressure) were identified with sensitivities of 57% and 67% and specificities of 72% and 62% respectively. Compared with those with waist measurements below Action Levels, age and lifestyle adjusted odds ratios for having at least one risk factor were 2.2 (95% confidence interval: 1.8, 2.8) in men with a waist measurement of 94-102 cm and 1.6 (1.3, 2.1) in women with a waist measurement of 80-88 cm. In men and women with larger waist measurements these age and lifestyle adjusted odds ratios were 4.6 (3.5,6.0) and 2.6 (2.0,3.2) respectively.

Conclusions: Waist circumference identifies people at with increased cardiovascular risks.

INTRODUCTION

Lean *et al* (1995; see **Chapter 4.1**) recently proposed waist circumference as a simple measurement to indicate the need for weight management. Waist circumference related both to body mass index and waist to hip ratio. Two Action Levels of waist circumference were determined to identify people whose health risks were increasing (Action Level 1: men 94 cm, women 80 cm) or high (Action Level 2: men 102 cm, women 88 cm).

The ongoing Dutch Monitoring Project on Risk Factors for Chronic Diseases (MORGEN project) which started in 1993, offered the opportunity in a large sample of men women to validate the Action Levels in a large sample of men and women and to assess the prevalence of cardiovascular risk factors and relative risks of subjects according to their waist circumference.

METHODS

Subjects

A random sample of 2183 men and 2698 women aged 20-59 years was selected from the civil registry in Amsterdam, Maastricht and Doetinchem. Sampling was part of the MORGEN-project to determine the prevalence of risk factors for chronic diseases, and also other specific chronic conditions in the general population living in various parts of The Netherlands. Measurements were made in basic health services in Amsterdam (in the West), Doetinchem (a small town in the East) and Maastricht (in the South). To obtain similar numbers of subjects at each age we stratified the sample by sex and five year age group. The response rate to invitations was roughly 50% in Amsterdam and Maastricht, and 80% in Doetinchem. All measurements were by trained investigators.

Anthropometry

Body weight in light clothes was measured to the nearest 0.1 kg, and height to the nearest 0.5 cm. Body mass index was calculated as weight (kg) divided by height (m^2). Waist circumference midway between lower rib and iliac crest and hip circumference at the level of the great trochanters were measured in duplicate to the nearest mm using flexible tape (WHO, 1989).

Cardiovascular risk factors

Sitting blood pressure was measured using a random zero sphygmomanometer, small (9 × 18 cm), medium (12 × 23 cm) and large (15 × 33 cm) cuffs being used as appropriate. Systolic (Korotkoff phase I) and diastolic (Korotkoff phase V) blood pressure was measured twice on the left upper arm and the average used for analysis. Total and high density lipoprotein cholesterol concentrations were determined enzymatically with a Boehringer kit (Katterman *et al*, 1984). High density lipoprotein was isolated by precipitating apolipoprotein B containing lipoproteins with magnesium phosphotungstate (Lopes-Virella *et al*, 1977). All cholesterol analyses were performed at the clinical chemistry laboratory, University Hospital of Dijkzigt, Rotterdam, under standardisation programmes (World Health Organisation Regional Lipid Centre for Europe in Prague, Czechoslovakia, and the Centres for Disease Control, Atlanta).

Analysis

Hypercholesterolaemia was defined as plasma cholesterol ≥6.5 mmol/l (European Atherosclerosis Society, 1987; WHO, 1988), low high density lipoprotein-cholesterol as ≤0.9 mmol/l (European Atherosclerosis Society, 1987), and hypertension as systolic blood pressure ≥160 mmHg, or diastolic blood pressure ≥95 mmHg, or use of antihypertensive agents (WHO, 1988). Subjects were placed in either of two categories for each of three lifestyle factors: smoking (current cigarette smokers or non-smokers), drinking (alcohol drinkers or non-drinkers), and physical activity (affirmative or negative answers to the question "Are you performing sports, including jogging and fitness training?").

Statistical methods

Sensitivity was defined as the percentage of all subjects with a risk factor who were identified correctly by high (above Action Level) waist circumference, and specificity as the percentage of all subjects without a risk factor who were identified correctly by low (below Action Level) waist circumference. Positive prediction was calculated as the percentage of subjects with a waist circumference above Action Level who had the risk factor, and negative prediction as the percentage of subjects with a waist circumference below Action Level who did not have a risk factor (Sturmans, 1984; Swinscow, 1983).

Linear regression analysis and partial correlations were used to determine the relationships between variables. Logistic regression analysis was employed to determine the relative risk of prevalence of cardiovascular risk factors for subjects categorised by the two waist circumference Action Levels, with adjustments for age, alcohol consumption, cigarette smoking, physical activity, and education level. We did not adjust for body mass index and waist to hip ratio because of multicollinearity with waist circumference (Belsley *et al*, 1980). Height accounted for less than 0.3% of variance in waist circumference and was excluded from the analysis. Statistical analyses used the SAS/STAT computer programme (SAS Institute, Philadelphia).

Cross tabulation was used to determine the sensitivity and specificity (Sturmans, 1984) of waist circumference Action Levels defined by Lean *et al* (1995; **Chapter 4.1**), Action Level 1: men 94 cm, women 80 cm; Action Level 2: men 102 cm and women 88 cm - to identify subjects with body mass index values above 25 or above 30 kg/m^2 for men and for women (the conventional cut-off points) and waist to hip ratio above 0.95 for men and 0.80 for women. Cross tabulation with waist measurement cut-offs defined by Lean *et al* (1995; **Chapter 4.1**) at Action Levels 1 and 2 were used to determine the sensitivity, specificity, and positive and negative predictions (Sturmans, 1984) of cardiovascular risk factors (high cholesterol concentration, low high density lipoprotein concentration, hypertension) at levels defined by the World Health Organisation (1989) and the European Atherosclerosis Society (1987).

RESULTS

Mean age, body mass index, hip circumference and total plasma cholesterol were similar in men and women. Men had a higher waist circumference, waist to hip ratio and blood pressure and lower high density lipoprotein cholesterol concentration (**Table 5.2.1**).

1. Replication of Action Levels to identify subjects with high body mass index and high waist to hip ratio

The Action Levels defined by Lean *et al* (1995; **Chapter 4.1**), using waist circumference (Action Level 1: men 94 cm, women 80 cm; Action Level 2: men 102 cm, women 88 cm), were applied to this sample to identify subjects with a high body mass index ($\geq$25 or $\geq$30 kg/m^2 in men and in women) and high waist to hip ratio ($\geq$0.95 in men, $\geq$0.80 in women). Sensitivity was over 97.5% and specificity over 96.0% with only 2% false positive results and 0.8% false negative results with Action Level 1 and 1.4% false positive results and 0.3% false negative results in Action Level 2 for the entire sample (**Table 5.2.2**).

2. Implications of Action Levels on cardiovascular risk factors

The prevalence (**Figure 5.2.1**) and mean (**Table 5.2.3**) values of adverse cardiovascular risk factors (except decreases in high density lipoprotein cholesterol concentration) increased with waist circumference in men and women. Correlations of waist circumference, body mass index and waist to hip ratio with risk factors (total cholesterol concentration, high density lipoprotein cholesterol concentration, systolic and diastolic blood pressure) were similar and remained significant in partial correlations controlling for age, alcohol consumption, cigarette smoking, physical activity and education (**Table 5.2.4**).

Sensitivity and specificity for identifying risk factors from waist circumference (**Table 5.2.5**) at Action Level 1 were between 57-72% both in men and women, with positive prediction varying between 16-38% in men and 10-22% in women for individual risk factors. Positive prediction increased to 59% in men and 37% in women who had one or more risk factors. Negative prediction was much higher, varying between 81 and 96% for individual risk factors and 71% in men and 85% in women who did not have any risk factors. Both positive and negative predictions by Action Level 1 were higher than the prevalence of subjects with (positive) and without (negative) risk factors in the whole population. Positive predictions of cardiovascular risk factors increased further in subjects identified by Action Level 2, with a reduction in negative prediction (**Table 5.2.5**).

The relative risk of adverse cardiovascular risk factors identified by using odds ratios (adjusted for age, alcohol consumption, cigarette smoking, physical activity and education levels by logistic regression) with reference to subjects with waist circumference below Action Level 1, increased significantly as waist circumferences rose above Action Levels 1 and 2 (**Table 5.2.6**; data adjusted for age, and lifestyle). For health promotion simple waist circumference cut-off points would be used. Differences in prediction with or without adjustments were similar, with the same patterns of relative risks (data not shown).

DISCUSSION

The present study supports our earlier finding that waist Action Levels identify those with high body mass and central fat distribution with high sensitivity and specificity (**Chapter 4.1**; Lean *et al*, 1995). In addition, the study shows a close relation between waist circumference and cardiovascular risk factors. Waist circumference cut-off measurement identified (positive prediction) cardiovascular risk factors at one and a half times to twice the prevalence in the whole population at Action Level 1 and two and a half to three times at Action Level 2 (**Table 5.2.6**). Negative prediction by the Action Levels remained higher than the prevalence in the entire population. These results suggest that Action Levels using waist circumference may provide a valuable, simple method for alerting people at increased risk of cardiovascular disease who might benefit from weight management. The risk factor criteria used (cholesterol concentration ≥6.5

mmol/l, high density lipoprotein concentration ≤0.9 mmol/l, blood pressure ≥160/95 mmHg) are conservative. Figures for risk prevalence would be higher if lesser levels of risk were assessed.

Waist circumference has previously been related to cardiovascular risk factors (Higgins *et al*, 1988; Kannel *et al*, 1991; Seidell *et al*, 1992). In this study waist circumference correlated similarly to body mass index and waist to hip ratio with most of the cardiovascular risk factors. Adjusting for influences such as age, education and lifestyle had little effect. Higgins *et al* (1988) reached similar conclusions in the Framingham study, showing that waist circumference was associated with 24 year age adjusted mortality and also that waist circumference gave better risk prediction amongst smokers. In this study after adjustment for age and other lifestyle factors, smokers of both sexes had consistently more cardiovascular risk factors than non-smokers in any category of waist circumference (results not shown). With increasing age the serum cholesterol concentration increases substantially in women. Covariance between age and waist measurement prevents further increase in predictive power of waist circumference for high cholesterol concentration above Action Level 2.

Seidell (1995c) reviewed anthropometric methods to assess abdominal fat, concluding that waist circumference alone was probably the most practical measurement for use in health promotion. For that purpose, practical cut-off measurements of waist circumference are required. Waist circumference relates closely to intra-abdominal fat mass (Seidell *et al*, 1988; Ross *et al*, 1992; Ross *et al*, 1993; Pouliot *et al*, 1994), and changes in waist circumference reflect changes in cardiovascular risk factors (Sönnichsen *et al*, 1992; Wing *et al*, 1992; Wing *et al*, 1995; Hellenius *et al*, 1993). Positive prediction of individual risk factors was fairly low but increased considerably when one or more of the risk factors were being identified (**Table 5.2.5**). Recent studies find large waist circumference strongly associated with risk factors of insulin resistance syndrome in women (Edwards *et al*, 1994) and non-insulin-dependent diabetes mellitus in men (Chan *et al*, 1994), and risks of breast cancer in women (den Tonkelaar *et al*,

1995) and colonic cancer in men (Giovannucci *et al*, 1995), suggesting that waist circumference may have a wider value as a measure for total health risks.

CONCLUSIONS

Action Levels of waist circumference proposed previously could be employed to identify sections of the population at high risk of chronic disease from high total plasma cholesterol concentration, low high density lipoprotein cholesterol concentration, and hypertension who might benefit from weight management.

Table 5.21. Physical and metabolic characteristics of 2183 men and 2698 women.

	Men		Women	
	Mean	SD	Mean	SD
Age (years)	42.7	10.5	42.5	10.7
Weight (kg)	81.4	11.9	68.3	11.3
Height (cm)	177.9	7.4	165.1	6.8
Body mass index (kg/m^2)	25.7	3.4	25.1	4.2
Waist circumference (cm)	91.6	10.4	80.3	10.9
Hip circumference (cm)	101.7	6.4	102.1	8.3
Waist to hip ratio	0.90	0.07	0.79	0.07
Total cholesterol (mmol/l)	5.4	1.1	5.4	1.1
HDL cholesterol (mmol/l)	1.1	0.3	1.4	0.4
Systolic blood pressure (mmHg)	122.8	15.6	115.5	15.4
Diastolic blood pressure (mmHg)	77.8	10.4	74.1	9.9

HDL = high density lipoprotein.

Table 5.2.2. False positive and false negative findings, sensitivity and specificity in categorising men and women by waist circumference to identify those with body mass index ≥25 at Action Level 1 or ≥30 kg/m^2 at Action Level 2 and those with lower body mass index but waist to hip ratio ≥0.95 (men) or ≥0.80 (women).

Action Level of waist circumference	cm	False positive	False negative	Sensitivity (%)	Specificity (%)
		Men (n = 2183)			
Action Level 1	≥94 cm	40/1035	22/475	97.42	97.03
Action Level 2	≥102 cm	45/1603	7/151	97.80	97.61
		Women (n = 2698)			
Action Level 1	≥80 cm	59/1219	16/710	98.64	96.17
Action Level 2	≥88 cm	22/1778	6/303	98.99	98.96

True positive describes people with high body mass index and those with lower body mass index but high waist to hip ratio, correctly identified by waist circumference above Action Level. True negative describes people with low body mass index and those with higher body mass index but low waist to hip ratio. False positive describes people with waist circumference above Action Level but low body mass index and low waist to hip ratio. False negative describes people with waist circumference below Action Level but with high body mass index and high waist to hip ratio. These numbers were used to determine the sensitivity and specificity (Sturmans, 1984).

Table 5.2.3. Mean serum lipid concentrations and blood pressure of men and women in different categories of waist circumference.

Waist circumference (cm)	n	Total cholesterol (mmol/l) Mean (SE)	HDL cholesterol (mmol/l) Mean (SE)	Systolic blood pressure (mmHg) Mean (SE)	Diastolic blood pressure (mmHg) Mean (SE)
Men (n = 2183)					
<94	1312	5.17 (0.03)	1.15 (0.01)	119.4 (0.4)	75.3 (0.3)
94-<102	515	5.71 (0.05)	1.04 (0.01)	126.8 (0.6)	80.4 (0.4)
≥102	356	5.88 (0.06)	0.98 (0.02)	129.6 (0.7)	83.4 (0.4)
Women (n = 2698)					
<80	1481	5.14 (0.03)	1.47 (0.01)	111.2 (0.4)	71.3 (0.2)
80-<88	608	5.59 (0.04)	1.37 (0.01)	117.5 (0.6)	75.4 (0.4)
≥88	609	5.78 (0.04)	1.26 (0.01)	123.9 (0.6)	79.6 (0.4)

All categories significantly different (analysis of variance), P <0.001; HDL = high density lipoprotein.

Table 5.2.4. Correlation coefficients between waist circumference, body mass index and waist to hip ratio and risk factors unadjusted and adjusted for alcohol consumption, cigarette smoking, physical activity, education levels and age.

	Waist circumference		Body mass index		Waist to hip ratio	
	Un-adjusted	Adjusted	Un-adjusted	Adjusted	Un-adjusted	Adjusted
			Men (n = 2183)			
Total cholesterol	0.344	0.232	0.319	0.247	0.335	0.189
HDL cholesterol	-0.269	-0.305	-0.287	-0.311	-0.249	-0.292
Systolic blood pressure	0.336	0.249	0.306	0.239	0.348	0.244
Diastolic blood pressure	0.371	0.283	0.354	0.287	0.384	0.288
			Women (n = 2698)			
Total cholesterol	0.265	0.106	0.217	0.099	0.290	0.114
HDL cholesterol	-0.261	-0.280	-0.254	-0.245	-0.242	-0.269
Systolic blood pressure	0.372	0.237	0.335	0.226	0.301	0.188
Diastolic blood pressure	0.374	0.261	0.345	0.250	0.330	0.203

HDL = high density lipoprotein.

Table 5a. Prevalence, positive and negative prediction, sensitivity and specificity of high cholesterol concentration (≥6.5 mmol/l), low high density lipoprotein cholesterol concentration (≤0.9 mmol/l), hypertension (systolic pressure ≥160 mmHg or diastolic pressure ≥95 mmHg or treated) in men by waist circumference Action Levels.

Men (n = 2183)	Percentage (95% confidence interval)†				
		Prediction			
Risk factor	Prevalence‡	Positive	Negative	Sensitivity	Specificity
Action Level 1 (waist circumference ≥94 cm) (n = 871)					
High total cholesterol	14.8 (13.3, 16.3)	21.6 (18.9, 24.3)	89.7 (88.1, 91.4)	58.2 (54.9, 61.5)	63.3 (60.7, 65.9)
Low HDL cholesterol	26.4 (24.5, 28.2)	37.5 (34.3, 40.8)	81.0 (78.9, 83.1)	56.8 (53.5, 60.1)	66.2 (63.6, 68.7)
Hypertension	8.7 (7.6, 9.9)	15.6 (13.2, 18.0)	95.8 (94.7, 96.9)	71.2 (68.2, 74.2)	63.1 (60.5, 65.7)
One or more risk factors	41.1 (39.1, 43.2)	58.8 (55.5, 62.1)	70.6 (68.1, 73.0)	57.0 (53.7, 60.3)	72.1 (69.6, 74.5)
Action Level 2 (waist circumference ≥102 cm) (n = 356)					
High total cholesterol	14.8 (13.3, 16.3)	27.3 (22.6, 31.9)	87.6 (86.1, 89.1)	30.0 (25.3, 34.8)	86.1 (84.5, 87.7)
Low HDL cholesterol	26.4 (24.5, 28.2)	44.4 (39.2, 49.5)	77.1 (75.2, 79.0)	27.4 (22.8, 32.1)	87.7 (86.2, 89.2)
Hypertension	8.7 (7.6, 9.9)	21.6 (17.4, 25.9)	93.8 (92.7, 94.9)	40.3 (35.2, 45.4)	86.0 (84.4, 87.6)
One or more risk factors	41.1 (39.1, 43.2)	69.9 (65.2, 74.7)	64.5 (62.3, 66.7)	27.7 (23.1, 32.4)	91.7 (90.4, 92.9)

†Confidence intervals were calculated from SE percentage: $\sqrt{P(100-P)/n}$, where P represents one percentage, (100-P) represents the other, n is the number of subjects (Swinscow, 1983); ‡Prevalence of risk factors in total population; HDL = high density lipoprotein.

Table 5b. Prevalence, positive and negative prediction, sensitivity and specificity of high cholesterol concentration (≥6.5 mmol/l), low high density lipoprotein cholesterol concentration (≤0.9 mmol/l), hypertension (systolic pressure ≥160 mmHg or diastolic pressure ≥95 mmHg or treated) in women by waist circumference Action Levels.

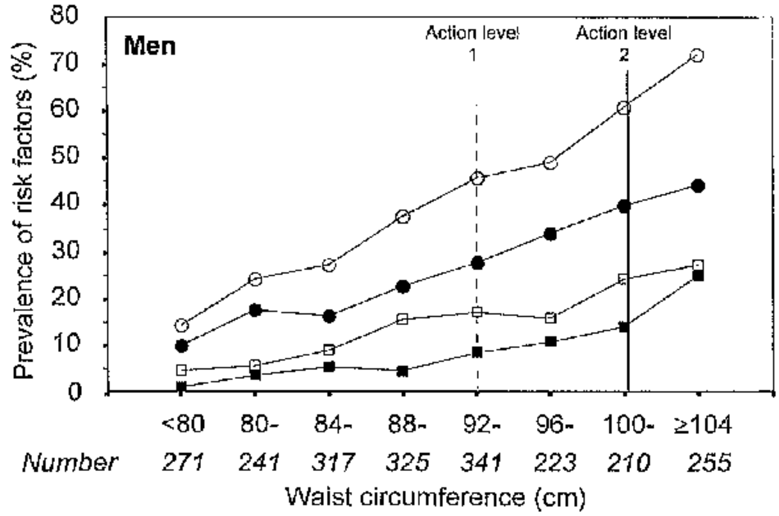
Women (n = 2698)	Percentage (95% confidence interval)†				
		Prediction			
Risk factor	Prevalence‡	Positive	Negative	Sensitivity	Specificity
	Action Level 1 (waist circumference ≥80 cm) (n = 1217)				
High total cholesterol	14.4 (13.5, 16.2)	21.5 (19.2, 23.8)	90.6 (89.1, 92.1)	65.3 (62.7, 68.0)	58.4 (55.9, 60.9)
Low HDL cholesterol	6.9 (6.0, 7.9)	10.0 (8.3, 11.7)	95.6 (94.6, 96.7)	65.2 (62.6, 67.9)	56.4 (53.9, 58.9)
Hypertension	7.3 (6.4, 8.3)	13.0 (11.9, 14.9)	97.3 (96.5, 98.1)	79.8 (77.5, 82.1)	57.6 (55.1, 60.2)
One or more risk factors	25.4 (23.7, 27.0)	37.4 (34.7, 40.1)	84.5 (82.7, 86.4)	66.5 (63.9, 69.2)	62.2 (59.7, 64.6)
	Action Level 1 (waist circumference ≥88 cm) (n = 609)				
High total cholesterol	14.4 (13.5, 16.2)	22.8 (19.5, 26.2)	87.5 (86.0, 88.9)	34.7 (30.9, 38.4)	79.5 (77.8, 81.3)
Low HDL cholesterol	6.9 (6.0, 7.9)	14.0 (11.2, 16.7)	95.1 (94.2, 96.0)	45.5 (41.5, 49.4)	79.1 (77.4, 80.9)
Hypertension	7.3 (6.4, 8.3)	18.4 (15.3, 21.5)	95.9 (95.0, 96.7)	56.6 (52.6, 60.5)	80.1 (78.4, 81.8)
One or more risk factors	25.4 (23.7, 27.0)	44.3 (40.4, 48.3)	80.2 (78.5, 81.9)	39.5 (35.6, 43.4)	83.2 (81.6, 84.8)

†Confidence intervals were calculated from SE percentage: $\sqrt{P(100-P)/n}$, where P represents one percentage, (100-P) represents the other, n is the number of subjects (Swinscow, 1983); ‡Prevalence of risk factors in total population; HDL = high density lipoprotein.

Table 6. Prevalence and odds ratios of high cholesterol concentration (≥6.5 mmol/l), low high density lipoprotein cholesterol concentration (≤0.9 mmol/l), and hypertension (systolic pressure ≥160 mmHg or diastolic pressure ≥95 mmHg or treated) in different categories of waist circumference adjusted for age, alcohol consumption, cigarette smoking, physical activity and education in men and women by waist circumference Action Levels.

	High total cholesterol		Low HDL cholesterol		Hypertension		One or more risk factors	
Waist (cm)	Prevalence (%)	Odds ratio (95% confidence interval)	Prevalence (%)	Odds ratio (95% confidence interval)	Prevalence (%)	Odds ratio (95% confidence interval)	Prevalence (%)	Odds ratio (95% confidence interval)
Men (n = 2183)								
<94	10.3	1.00	19.0	1.00	4.2	1.00	29.4	1.00
94-<102	17.7	1.38 (1.02, 1.87)	32.8	2.37 (1.85, 3.04)	11.5	1.98 (1.33, 2.95)	51.1	2.23 (1.78, 2.78)
≥102	27.2	2.29 (1.67, 3.14)	44.4	3.64 (2.75, 4.80)	21.6	4.03 (2.72, 5.96)	69.9	4.57 (3.48, 5.99)
Women (n = 2698)								
<80	9.4	1.00	4.4	1.00	2.7	1.00	15.5	1.00
80-<88	20.2	1.51 (1.14, 2.00)	6.1	1.54 (1.00, 2.38)	7.6	1.84 (1.17, 2.88)	30.4	1.64 (1.30, 2.08)
≥88	22.8	1.42 (1.06, 1.89)	14.0	3.80 (2.59, 5.59)	18.4	4.23 (2.83, 6.33)	44.3	2.55 (2.02, 3.23)

HDL = high density lipoprotein.



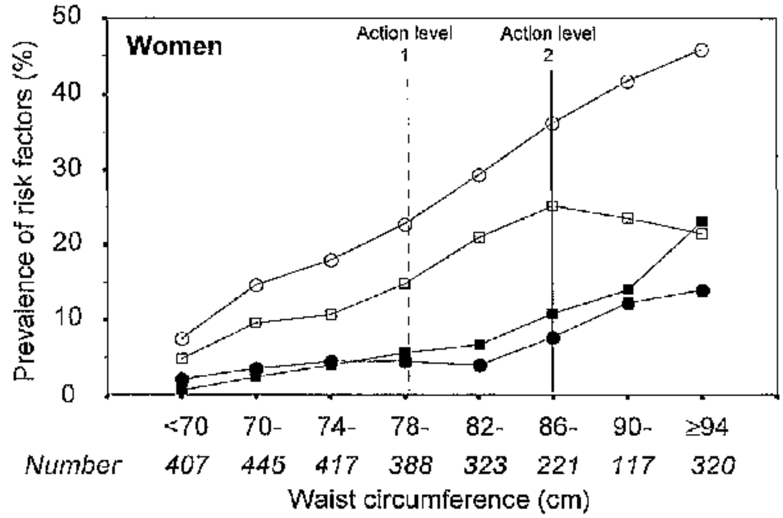


Figure 5.2.1. Prevalence rates of men and women with low high density lipoprotein cholesterol concentration (≤9 mmol/l), hypercholesterolaemia (≥6.5 mmol/l), hypertension (treatment with hypertensive agents, or systolic pressure ≥160 mmHg, or diastolic pressure ≥95 mmHg), and any one or more risk factors.

— 5.3 —

THE PREVALENCE OF LOW BACK PAIN AND ASSOCIATIONS WITH BODY FATNESS, FAT DISTRIBUTION AND HEIGHT

This section has been peer reviewed and will be published as

Han TS, Schouten JSAG, Lean MEJ, Seidell JC. The prevalence of low back pain and associations with body fatness and fat distribution and height. *International Journal of Obesity* 1997 (in press).

Collaboration with MORGEN project

ABSTRACT

Objective: To examine the associations of low back pain symptoms with waist circumference, height, waist to hip ratio and body mass index, and to test the interactions between (1) waist circumference and height, and (2) waist to hip ratio and body mass index.

Setting: Cross-sectional study set in The Netherlands of random sample of 5887 men and 7018 women aged 20-60 years.

Results: The prevalences of low back pain in men and women in the past 12 months were 46% and 52%, of whom 17% and 21% had low back pain for a total of 12 or more weeks, and 13% and 18% had symptoms suggestive of intervertebral disc herniation. After adjustments for age, smoking and education, more women in the highest tertile of waist circumference reported low back pain in the past 12 months (odds ratio = 1.2, 95% confidence interval: 1.1 to 1.4), low back pain for a total of 12 or more weeks (odds ratio = 1.5, 95% confidence interval: 1.3 to 1.8), and intervertebral disc herniation symptoms (odds ratio = 1.3, 95% confidence interval: 1.1 to 1.6) than women in the lowest waist tertile. Corresponding values of low back pain symptoms for women with high body mass index or high waist to hip ratio were similar to those with high waist. There were no significant differences between men in different tertiles of waist, waist to hip ratio or body mass index reporting low back pain symptoms. Tallest subjects did not report low back pain symptoms more often than shortest subjects. There were no significant interactions between waist and height or between waist to hip ratio and body mass index on low back pain symptoms.

Conclusion: Women who are overweight or with a large waist have a significantly increased likelihood of low back pain. There are no significant interactions between waist and height, or waist to hip ratio and body mass index on low back pain symptoms.

Key words: body mass index, fat distribution, low back pain, obesity, stature, weight.

INTRODUCTION

Low back pain is one of the commonest symptoms in Western societies, responsible for an enormous burden of chronic disease, and is associated with high medical health care and social costs (Wells, 1985). Overweight, indicated by high body mass index is associated with poor subjective ill health and poor musculoskeletal functioning (Seidell *et al*, 1986a). Overweight persons more frequently seek medical care for back/joint/muscle complaints (Seidell *et al*, 1986b).

It is generally assumed that overweight and low back pain are related (Popkess-Vawter and Patzel, 1992). However, scientific evidence to support this relationship is scanty (Garzillo and Garzillo, 1994) and some is conflicting (Brennan *et al*, 1987; Croft and Rigby, 1994; Wright *et al*, 1995). Associations between body fat distribution and low back pain are not well documented, although it may be postulated that subjects who carry excessive abdominal fat mass over a long period may be at risk of low back pain, as a result of altered posture to counterbalance the protruding fat mass. Prolapsed intervertebral disc is commonly believed to be more frequent in taller people (Heliövaara, 1987). Height may relate independently to low back pain from large abdominal fat mass, and may aggravate back pain associated with stooping especially in those with large waist or large abdominal fat mass. These persons may require more reactive forces to counteract the gravitational pull on this fat mass to achieve balance, especially when bending forward for lifting or when walking down stairs, as a result, more strain may be exerted on their lower back. The same hypothesis could be proposed for those with central fat distribution, indicated by high waist to hip ratio, who may be at increased risk of low back pain independently from total fatness, measured by body mass index.

The present study examined the associations of low back pain symptoms with waist circumference, height, waist to hip ratio and body mass index, and to test the interactions between (1) waist circumference and height, and (2) waist circumference to hip ratio and body mass index on low back pain symptoms.

METHODS

Subjects

In the present study, the 1993 to 1995 cohorts were available from the ongoing MORGEN (Monitoring of Risk Factors and Health in The Netherlands) project, which is undertaken as a public health surveillance to monitor chronic diseases, risk factors and their consequences. Subjects were randomly recruited from three towns, Amsterdam, Maastricht and Doetinchem. To obtain similar numbers of subjects at each age, the sample was stratified by sex and five year age group. The numbers of 5887 men and 7018 women aged 20-60 years in the present study represent those who attended the health centres for measurements including anthropometry. Those who did not attend the health centres or were of non-Dutch nationality were excluded from analyses.

Measurements

Symptoms of low back pain were obtained from questionnaire. Those who responded affirmatively to having low back pain in the past 12 months, were then asked whether they had radiating pain to the knees or feet, to indicate symptoms of intervertebral disc herniation. This symptom was only accepted in the presence of low back pain, to avoid including those with other causes of radiated pain. The subjects were asked about the total duration of low back pain in the past 12 months. Those who had low back pain for a total of twelve weeks or more were classified as having chronic low back pain. The reference groups for the three classes of low back pain were composed of those who did not fulfil the criteria for the symptom under analysis, thus the reference group when analysing one symptom included some subjects with other symptom(s) of low back pain.

All anthropometric measurements were made according to the World Health Organisation (1995) recommendations by trained field scientists. Subjects wore light clothes during measurements of body weight to the nearest 100g using calibrated scales, height in bare feet to the nearest mm, waist circumference in duplicate at the level between the lowest rib margin and iliac crest, and hip circumference at the widest trochanters to the nearest mm. Waist to hip circumferential ratio was computed, and body mass index was calculated as weight (kg) divided by height squared (m^2).

Males and females were analysed separately. Confounding factors were divided into classes for analysis. Age: 10 year groups (20-29 year group as reference), smoking: non-smokers, ex-smokers and current smokers (non-smokers as reference), educational levels: secondary education or lower, vocational or higher secondary education, and higher vocational or university education (higher vocational or university education as reference).

Statistical analysis

The prevalence of low back pain symptoms, using cross tabulation, were computed in quintiles of waist circumference, height, body mass index, and waist to hip ratio, and plotted to examine the type of curve for the relationships between low back pain symptoms and adiposity indices.

Statistical analyses were performed using SAS version 6.1 (Cary, USA). All cut-off points were decided before analysis. Tertiles of anthropometric variables in the present sample were identified at 86.9, 95.9 cm in men and 75.0, 84.0 cm in women for waist circumference; and 175.0, 181.5 cm in men and 162.5, 168.5 cm in women for height; 0.872, 0.936 in men and 0.756, 0.815 in women for waist to hip ratio; 24.1, 26.9 kg/m^2 in men and 22.8, 25.9 kg/m^2 in women for body mass index.

Logistic regression analysis was also performed to estimate the relative risks (odds ratios and 95% confidence intervals) of low back pain symptoms in different categories of anthropometry. Crude, age adjusted, and age, smoking status and educational level adjusted odds ratios were calculated.

The adjusted prevalence of low back pain symptoms in combination of tertiles of waist and height, and combination of tertiles of waist to hip ratio and body mass index were calculated using analysis of variance, adding age, smoking and education as covariates. Logistic regression analysis was used to estimate the maximum likelihood of the models to examine the interaction between waist circumference and height, and waist to hip ratio and body mass index. Calculations were made for the difference of log likelihood (χ^2) obtained in the model predicted by dummy variables of waist tertiles (two variables) and height tertiles (two variables) subtracted from χ^2 obtained in the same model with an addition of four dummy variables from combinations of waist tertile 2 and height tertile 2, waist tertile 2 and height tertile 3, waist tertile 3 and height tertile 2, and waist tertile 3 and height tertile 3, with reference to the group of lowest waist tertile combined with lowest height tertile. This analysis was repeated for waist to hip ratio and body mass index in the relationship with low back pain symptoms. Interaction between variables was considered if the resultant χ^2 value exceeded the 5% significance level (4 degrees of freedom).

RESULTS

Subject characteristics are shown in **Table 5.3.1. Tables 5.3.2a & b** and **Figures 5.3.1a & b** (only chronic low back pain was selected for illustration) show the prevalence of chronic low back pain and intervertebral disc herniation increased with increasing waist, waist to hip ratio, and body mass index in both men and women, with women having more complaints of low back pain symptoms than men. About half of the population studied had low back pain in the past 12 months, 20% reporting symptoms which lasted a total of twelve weeks or more, and 15% had symptoms of intervertebral disc herniation. The pattern between low back pain and height was weak in women but more consistent in men, with shortest men (tertile 1) showing the greatest frequency of low back pain symptoms. Examination of plots did not reveal any tendency to low back pain in the very tall.

The relative risks (odds ratios) of low back pain symptoms in those with anthropometric measurements in the upper two tertiles were compared to those in the lowest tertile

(**Table 5.3.3a** & **b**). Without adjustments, more subjects with large waist circumference, high waist to hip ratio and high body mass index reported symptoms of low back pain, with the exception of low back pain in the past 12 months in men. The relationships were weaker after adjustments for age, smoking and education, but more women with large waist circumference continued to report symptoms of low back pain than those with smallest waist circumference. Relative risks from being overweight, assessed by body mass index, were slightly lower than from those having large waist circumference for each symptom of low back pain. In women, high waist to hip ratio significantly associated only with chronic low back pain. There was no evidence of taller subjects being more at risk of low back pain than shorter subjects.

The age, smoking and education adjusted prevalence of low back pain symptoms (only chronic low back pain was selected for illustration) in different combinations of tertiles of waist and height (**Figures 5.3.2a** & **b**), and body mass index and waist to hip ratio (**Figures 5.3.3a** & **b**) were plotted. Analysis of maximum likelihood (adjusted for age, smoking and education) showed that waist circumference and height did not interact on any symptom of low back pain (χ^2 range 1.6-4.6, P >0.5) either in men or in women. the interaction between high waist to hip ratio and high body mass index on symptom of intervertebral disc herniation did not reach the 5% significance level in either men (χ^2 = 6.8, P <0.2) or women (χ^2 = 8.5, P <0.1). In men, little evidence for an interaction between waist to hip ratio and body mass index on chronic low back pain was observed (**Figure 5.3.3a**), but there was some suggestion for this effect in women (χ^2 = 8.0, P <0.1) (**Figure 5.3.3b**). There was no evidence for an interaction between waist and height or waist to hip ratio and body mass index on low back pain in the past 12 months in either sex. Thus, the present study did not find that stratification by height or body mass index was necessary when assessing the associations between low back pain and waist circumference, and waist to hip ratio respectively.

DISCUSSION

As well as investigating the associations between low back and pain and body mass, the present study examined its relationships with body fat distribution. Chronic low back pain (lasting a total of twelve weeks or more in the past 12 months), and symptoms of intervertebral disc herniation (low back pain during the past 12 months with radiating pain to the knees or feet) were more prevalent in those with increased abdominal fatness, indicated by large waist circumference, and in overweight subjects (high body mass index). After adjusting for confounding factors (aging, smoking and low educational level), no significant relationship remained between low back pain and any of the indices of adiposity in men. The relationships were stronger in women, and remained significant for waist circumference and body mass index. There was little evidence for any interactions between waist circumference and height, or body mass index and waist to hip ratio on symptoms of low back pain.

Using body mass index to indicate overweight may misclassify people with excessive muscularity rather than excessive fatness (Wellens *et al*, 1996), and does not take account of fat distribution. We have found that chronic low back pain (**Figures 5.3.3a & b**) or symptoms of intervertebral disc herniation (**Figures** not presented) were most common in those with high waist to hip ratio when they are overweight. A prolonged burden of excess weight may cause low back pain through increased load compression on the intervertebral discs (Eklund and Corlett, 1984), or increased stress on the spine when bending to lift objects or stepping down stairs. Excess central fat might have specific mechanical effects including altered gait, which may affect the efficiency of shock absorbance by the bearing joints, leading to increased stress and strain on the spine. Biomechanical studies in subjects with large abdominal fat mass, indicated by large waist circumference, may help clarify the aetiology of low back pain.

Crude odds ratios for chronic low back pain and symptoms of intervertebral disc herniation in different categories of indices of adiposity were all significant. The present study defined the symptom of chronic low back pain as a total of twelve or more weeks of back pain in the past 12 months. This cut-off point was arbitrary. Alternative analyses using 'low back pain lasting a total of seven weeks or more in the last 12 months', or employing reference group as those who did not have any low back pain in the past twelve months were also performed. The results obtained showed no substantial differences to the results presented herein. After adjustments for age, smoking and education, only women with high body mass index and large waist remained significantly at risk of low back pain. Age had the most powerful confounding effect (data not shown).

The analysis between indices of adiposity and low back pain is complicated by smoking, since smokers tend to have higher waist and smaller hips than expected compared to non-smokers (Shimokata *et al*, 1989). In the present study, smokers were at significantly increased risk of low back pain symptoms, independently from all the other factors considered (results not shown), confirming previous findings (Wright *et al*, 1995; Deyo and Bass, 1989). Data in the present study were not adjusted for occupation or physical activity because of their unknown causal relationships with low back pain. Education is probably a more valid adjustment than occupation in relation to low back pain, because occupations change.

Comparing the relative risks of low back pain in subjects of highest quintiles and lowest quintiles of anthropometry would increase the contrast (**Figure 5.3.1**), thus give higher odds ratios, but with wider 95% confidence intervals due to smaller numbers in each category. The odds ratios for symptoms of low back pain only changed by less than 0.1 unit (results not shown) when subjects in extreme quintiles of anthropometric measurements were compared instead of tertiles. To test interactions between measurements, employing tertiles was more appropriate, since very few subjects had a combination of body mass index in the highest quintile and waist to hip ratio in the lowest quintile.

Using unadjusted prevalence, there were more shorter subjects with low back pain. However older subjects are generally shorter than younger subjects (**Chapter 3.2**; Han and Lean, 1996; van Leer *et al*, 1992), due to both losses in height associated with aging and secular trends towards taller populations (van Leer *et al*, 1992). After age and lifestyle adjustments, there was no association between height and low back pain. Other evidence on symptoms of low back pain and height is conflicting. Heliövaara (1987) found men above 180 cm and women above 179 cm had 2 and 4 times the risk of herniated lumbar intervertebral disc compared to the those who were 10 cm shorter. Other studies have found no association between height and low back pain (Kelsey, 1975; Kelsey *et al*, 1984). A study of men and women with low back pain has shown spinal mobility decreases with increasing body weight, whilst height had negligible effects (Mellin, 1987).

CONCLUSIONS

There are no significant interactions between waist circumference and height or waist to hip ratio and body mass index in the relationships with symptoms of low back pain. Women who are overweight, or those with a predominant abdominal fat mass, indicated by large waist circumference, are at greatly increased risk of low back pain. Associations between anthropometric measures and low back pain are much weaker or non-significant in men. Although the relative risks of low back pain symptoms related to overweight or large waist circumference were comparatively low in women, the high prevalence of these symptoms indicates a huge burden on the health care resources attributable to overweight, and the absolute impact of overweight on low back pain imposes an enormous claim on medical care facilities (Wells, 1985).

Table 5.3.1. Characteristics of 5887 men and 7018 women.

	Men			Women		
	Mean	SD	Range	Mean	SD	Range
Age (years)	42.9	10.7	20.3-60.0	42.2	11.0	20.2-59.9
Weight (kg)	82.0	12.0	44.4-157.0	68.5	11.5	36.6-153.0
Height (cm)	178.4	7.3	152.0-210.0	165.7	6.7	134.5-190.0
Body mass index (kg/m^2)	25.8	3.5	15.7-50.1	25.0	4.2	14.9-58.3
Waist circumference (cm)	92.3	10.8	64.0-155.0	81.0	11.1	56.5-150.0
Hip circumference (cm)	101.8	6.6	69.0-150.0	102.2	8.4	76.4-165.0
Waist to hip ratio	0.905	0.072	0.621-1.369	0.791	0.070	0.567-1.302
Non-smokers (%)	30.5	—	—	36.1	—	—
Ex-smokers (%)	33.2	—	—	26.6	—	—
Current smokers (%)	36.3	—	—	37.4	—	—
Secondary education or lower	44.7	—	—	55.2	—	—
Vocational or higher secondary education	29.5	—	—	25.2	—	—
Higher vocational or university education	25.8	—	—	19.6	—	—

Table 5.3.2a. Prevalence of symptoms of low back pain in tertiles of anthropometric measurements in 5887 men.

	Low back pain in the past 12 months (%)	Chronic low back pain† (%)	Symptoms of intervertebral disc herniation‡ (%)
Total prevalence	45.6	16.6	13.4
Waist circumference tertile 1	45.2	13.3	10.2
Waist circumference tertile 2	44.1	15.5	12.9
Waist circumference tertile 3	47.5	20.7	16.7
χ^2§	5.0	40.9***	36.6***
Height tertile 1	47.7	19.6	15.4
Height tertile 2	44.0	16.0	12.3
Height tertile 3	45.6	14.6	12.6
χ^2§	5.5	17.9**	9.4**
Waist to hip ratio tertile 1	44.4	13.2	8.9
Waist to hip ratio tertile 2	46.1	16.4	14.3
Waist to hip ratio tertile 3	46.4	20.1	16.8
χ^2§	1.8	34.1***	55.2***
Body mass index tertile 1	43.3	13.6	9.9
Body mass index tertile 2	45.5	17.0	14.1
Body mass index tertile 3	48.1	20.3	16.1
χ^2§	9.3**	32.2***	33.3***

†Low back pain for a total of 12 weeks or more in the past 12 months; ‡low back pain with radiating pain to the knees or feet; §differences in prevalence between tertiles of anthropometry: ***P <0.001, **P <0.01.

Table 5.3.2b. Prevalence of symptoms of low back pain in tertiles of anthropometric measurements in 7018 women.

	Low back pain in the past 12 months (%)	Chronic low back pain† (%)	Symptoms of intervertebral disc herniation‡ (%)
Total prevalence	52.3	20.5	17.6
Waist circumference tertile 1	48.2	14.8	13.5
Waist circumference tertile 2	52.7	20.5	16.6
Waist circumference tertile 3	55.9	25.9	22.4
χ^2§	28.1***	89.2***	66.5***
Height tertile 1	52.7	23.1	19.3
Height tertile 2	52.0	19.2	17.5
Height tertile 3	52.3	19.5	16.2
χ^2§	0.2	13.1**	7.6*
Waist to hip ratio tertile 1	49.2	15.0	14.3
Waist to hip ratio tertile 2	51.4	21.1	16.3
Waist to hip ratio tertile 3	56.1	25.0	21.9
χ^2§	23.5***	72.4***	50.3***
Body mass index tertile 1	48.3	16.8	14.1
Body mass index tertile 2	53.1	20.0	16.1
Body mass index tertile 3	55.7	24.9	22.8
χ^2§	26.1***	48.6***	66.4***

†Low back pain for a total of 12 weeks or more in the past 12 months; ‡low back pain with radiating pain to the knees or feet; §differences in prevalence between tertiles of anthropometry: ***P <0.001, **P <0.01, *P <0.05.

Table 5.3.3a. Logistic regression analysis to predict low back pain by body mass index, waist to hip ratio, waist circumference and by height, entered the model individually, unadjusted and adjusted for age, smoking and education, in 5887 men.

Independent variables§	Low back pain in the past 12 months		Chronic low back pain†		Symptoms of intervertebral disc herniation‡	
	OR	95% CI	OR	95% CI	OR	95% CI
			Unadjusted			
Waist tertile 1	1.00		1.00		1.00	
Waist tertile 2	0.96	0.84, 1.09	1.19	1.00, 1.43	1.30*	1.06, 1.58
Waist tertile 3	1.10	0.97, 1.25	1.70***	1.43, 2.01	1.76***	1.46, 2.13
Height tertile 1	1.00		1.00		1.00	
Height tertile 2	0.86*	0.76, 0.98	0.78**	0.66, 0.92	0.77**	0.64, 0.93
Height tertile 3	0.92	0.81, 1.05	0.70***	0.59, 0.83	0.79*	0.66, 0.95
WHR tertile 1	1.00		1.00		1.00	
WHR tertile 2	1.07	0.94, 1.22	1.29**	1.08, 1.54	1.71***	1.40, 2.09
WHR tertile 3	1.08	0.96, 1.23	1.66***	1.40, 1.96	2.07***	1.70, 2.52
BMI tertile 1	1.00		1.00		1.00	
BMI tertile 2	1.09	0.96, 1.24	1.20*	1.01, 1.44	1.49***	1.23, 1.82
BMI tertile 3	1.22*	1.07, 1.38	1.61***	1.36, 1.91	1.74***	1.44, 2.11
			Adjusted for age, smoking and education			
Waist tertile 1	1.00		1.00		1.00	
Waist tertile 2	0.89	0.78, 1.02	0.94	0.78, 1.14	0.99	0.80, 1.21
Waist tertile 3	0.97	0.85, 1.12	1.13	0.94, 1.37	1.13	0.92, 1.39
Height tertile 1	1.00		1.00		1.00	
Height tertile 2	0.91	0.80, 1.03	0.93	0.79, 1.10	0.93	0.77, 1.12
Height tertile 3	1.00	0.88, 1.15	0.97	0.81, 1.17	1.15	0.94, 1.40
WHR tertile 1	1.00		1.00		1.00	
WHR tertile 2	0.97	0.85, 1.11	0.93	0.77, 1.13	1.24	1.00, 1.53
WHR tertile 3	1.00	0.79, 1.06	0.98	0.80, 1.19	1.23	0.99, 1.53
BMI tertile 1	1.00		1.00		1.00	
BMI tertile 2	1.05	0.93, 1.20	1.01	0.84, 1.21	1.23*	1.01, 1.51
BMI tertile 3	1.11	0.97, 1.28	1.15	0.96, 1.38	1.21	0.99, 1.49

OR= odds ratio; CI = confidence interval; WHR = waist to hip ratio; †Low back pain for a total of 12 weeks or more in the past 12 months; ‡low back pain with radiating pain to the knees or feet; §reference to tertile 1 (odds ratio = 1.00) of each anthropometric variable; *** P <0.001, ** P <0.01, * P <0.05.

Table 5.3.3b. Logistic regression analysis to predict low back pain by body mass index, waist to hip ratio, waist circumference and by height, entered the model individually, unadjusted and adjusted for age, smoking and education, in 7018 women.

Independent variables§	Low back pain in the past 12 months		Chronic low back pain†		Symptoms of intervertebral disc herniation‡	
	OR	95% CI	OR	95% CI	OR	95% CI
			Unadjusted			
Waist tertile 1	1.00		1.00		1.00	
Waist tertile 2	1.20**	1.07, 1.34	1.48***	1.27, 1.73	1.28**	1.08, 1.50
Waist tertile 3	1.36***	1.22, 1.53	2.01***	1.74, 2.33	1.85***	1.59, 2.16
Height tertile 1	1.00		1.00		1.00	
Height tertile 2	0.97	0.87, 1.09	0.79**	0.69, 0.91	0.89	0.76, 1.03
Height tertile 3	0.98	0.88, 1.10	0.81**	0.70, 0.93	0.81**	0.70, 0.94
WHR tertile 1	1.00		1.00		1.00	
WHR tertile 2	1.09	0.98, 1.23	1.51***	1.30, 1.76	1.16	0.99, 1.37
WHR tertile 3	1.32***	1.18, 1.48	1.89***	1.63, 2.19	1.68***	1.44, 1.95
BMI tertile 1	1.00		1.00		1.00	
BMI tertile 2	1.21**	1.08, 1.36	1.24**	1.07, 1.44	1.17	1.00, 1.38
BMI tertile 3	1.34***	1.20, 1.51	1.65***	1.43, 1.91	1.80***	1.55, 2.09
			Adjusted for age, smoking and education			
Waist tertile 1	1.00		1.00		1.00	
Waist tertile 2	1.12	1.00, 1.27	1.26**	1.08, 1.48	1.06	0.90, 1.25
Waist tertile 3	1.21**	1.06, 1.37	1.49***	1.27, 1.75	1.32***	1.12, 1.57
Height tertile 1	1.00		1.00		1.00	
Height tertile 2	1.03	0.91, 1.16	0.89	0.77, 1.03	1.00	0.86, 1.17
Height tertile 3	1.12	0.99, 1.26	1.06	0.91, 1.22	1.06	0.91, 1.25
WHR tertile 1	1.00		1.00		1.00	
WHR tertile 2	1.02	0.91, 1.15	1.27**	1.09, 1.50	0.95	0.80, 1.12
WHR tertile 3	1.14*	1.01, 1.30	1.35***	1.15, 1.58	1.14	0.96, 1.35
BMI tertile 1	1.00		1.00		1.00	
BMI tertile 2	1.15*	1.02, 1.29	1.07	0.92, 1.24	1.00	0.85, 1.18
BMI tertile 3	1.21**	1.06, 1.37	1.23**	1.05, 1.44	1.35***	1.15, 1.60

OR= odds ratio; CI = confidence interval; WHR = waist to hip ratio; †Low back pain for a total of 12 weeks or more in the past 12 months; ‡low back pain with radiating pain to the knees or feet; §reference to tertile 1 (odds ratio = 1.00) of each anthropometric variable; ***P <0.001, **P <0.01, *P <0.05.

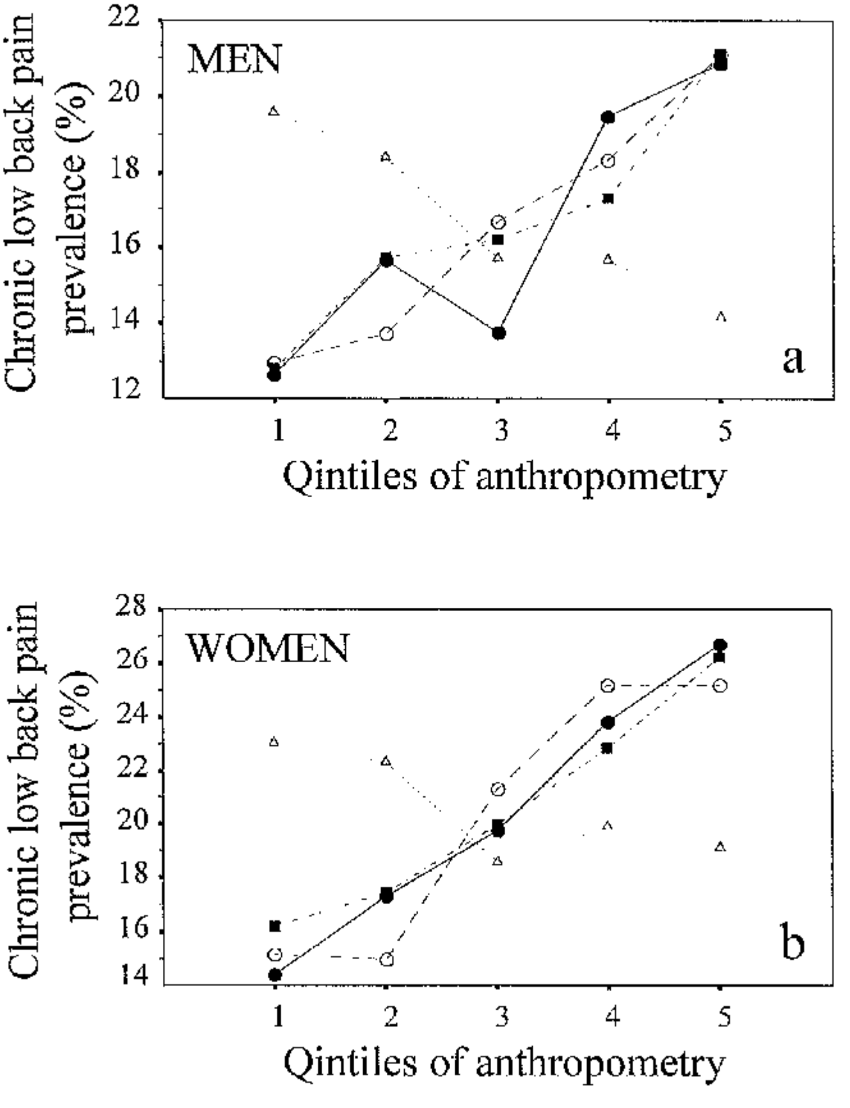
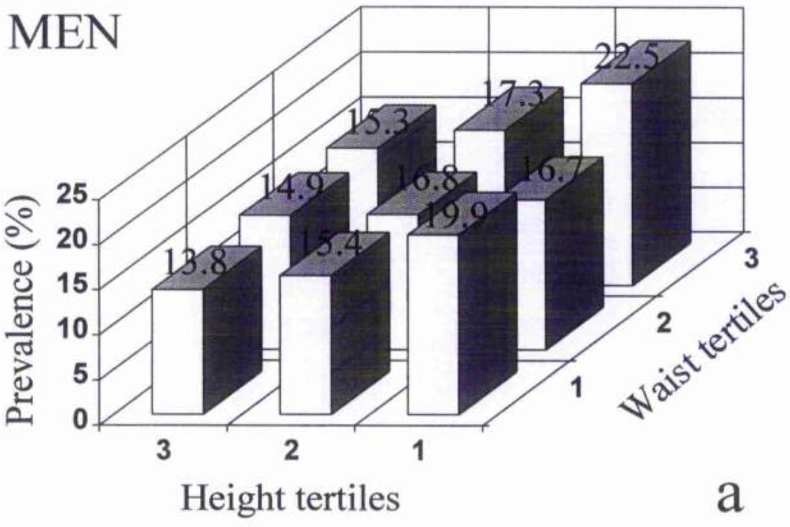


Figure 1. Plots of the prevalence of chronic low back pain against quintiles of anthropometry: ● waist circumference, Δ height, ○ waist to hip ratio, and ■ body mass index in 5887 men (a) and in 7018 women (b).



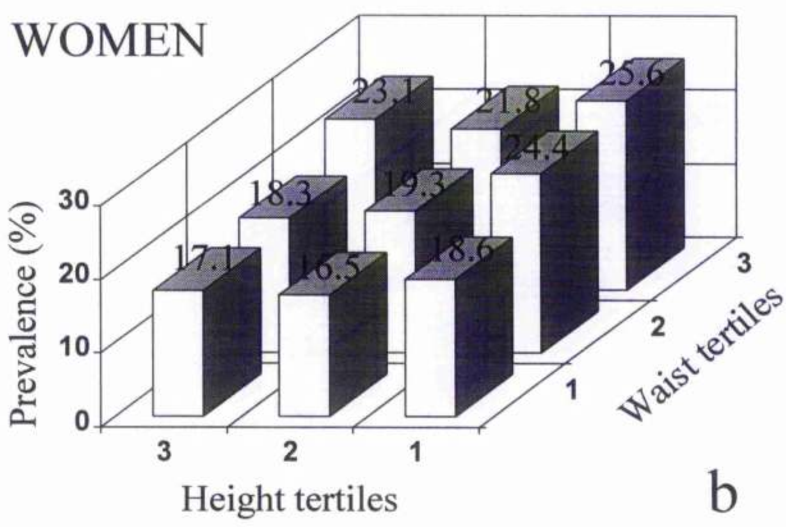
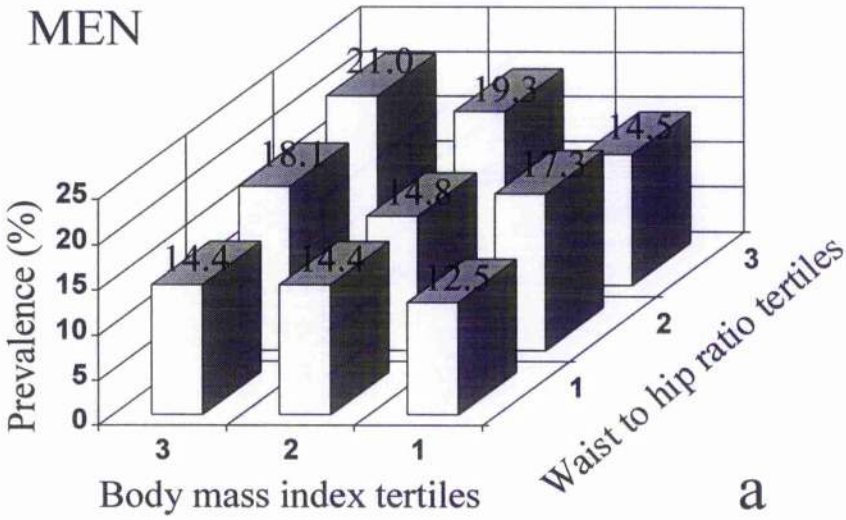


Figure 2. Prevalence (adjusted for age, smoking and education) of chronic low back pain in tertiles of waist circumference and tertiles of height in 5887 men (a) and in 7018 women (b).



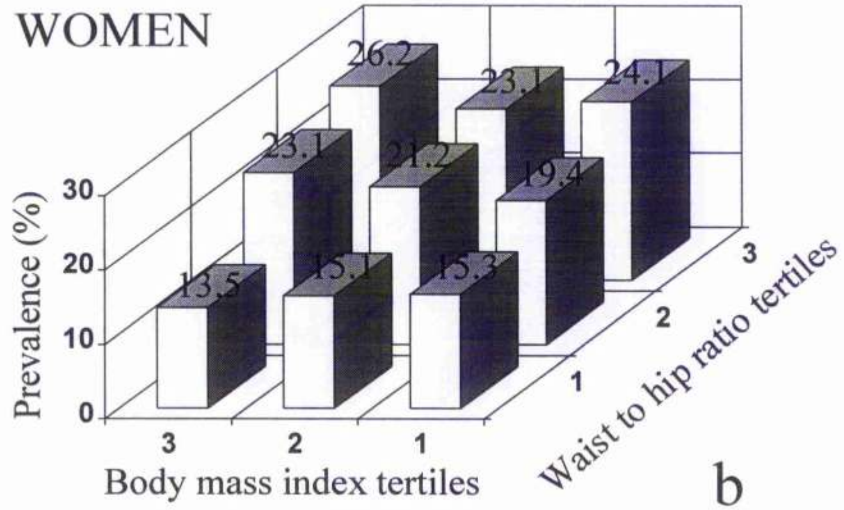


Figure 3. Prevalence (adjusted for age, smoking and education) of chronic low back pain in tertiles of waist to hip ratio and tertiles of body mass index in 5887 men (a) and in 7018 women (b).

— 5.4 —

SYMPTOMS OF RESPIRATORY INSUFFICIENCY IN RELATION TO BODY FAT AND FAT DISTRIBUTION

This section has been submitted for publication as

Han TS, Smit HA, Lean MEJ, Seidell JC. Symptoms of respiratory insufficiency in relation to fat and fat distribution. (submitted).

Collaboration with MORGEN project

ABSTRACT

Objective: To relate respiratory symptoms to measures of abdominal fat distribution and overweight, in people with and without evidence of underlying lung disease.

Design: Random sample of 5887 men and 7018 women aged 20-59 years, in a cross-sectional study set in The Netherlands.

Measures: Shortness of breath, wheezing, coughing, and bringing up phlegm.

Results: Compared to the lowest tertile with adjustments for age and lifestyle factors, those with waist circumference in the highest tertile were 2.4 times (95% confidence intervals 2.0 to 3.0) in men and 2.6 times (2.2 to 3.0) in women more likely to have shortness of breath when walking uphill or upstairs, 1.8 times (1.4 to 2.4) in women to be woken up by shortness of breath. Women with large waist were about 1.5 times more likely to wheeze when not having a cold, to cough or to bring up phlegm for more than 3 months a year. Respiratory symptoms related to body mass index or to waist to hip ratio were similar to waist circumference. The relationships with shortness of breath were present as aggravating factors in smokers and people with indicators of underlying lung disease (wheeze, chronic productive cough), and remained as symptoms of abdominal fat distribution or overweight in non-smokers and those without evidence of any underlying lung disease.

Conclusions: Increased waist circumference, body mass index and waist to hip ratio all associate with a variety of respiratory symptoms. These important symptoms of abdominal fat distribution and overweight represent an important burden of ill health at a population level.

Keywords: Health promotion, lung disease, obesity, quality of life, smoking.

INTRODUCTION

The prevalence of overweight, body mass index (weight/height^2) greater than 30 kg/m^2, in Western countries is more than 10% (Bennett *et al*, 1995; Kuczmarski *et al*, 1994; Seidell, 1995a). These persons are at increased risk of many chronic diseases such as diabetes, cardiovascular diseases and premature death (Manson *et al*, 1995; Simopoulos and van Itallie, 1984). Extreme overweight is associated with poor lung function (Luce, 1980; Zerah *et al*, 1993). Compared to non-overweight subjects, the total work of breathing while at rest in overweight subjects is about twice as high (Sharp *et al*, 1964). Decreased respiratory compliance is thought to play an important role. Luce (1980) has suggested that decreased chest wall compliance associated with overweight (Sharp *et al*, 1964a; Naimark and Cherniak, 1960) may be explained by the accumulation of fat in and around the ribs, diaphragm and abdomen. Respiratory compliance in these subjects has been observed to markedly reduce when lying recumbent, it was calculated that the mass loading of excessive fat mass was similar to having weight loaded on a person (Sharp *et al*, 1964b). Large abdominal fat mass may compress the lungs, which may cause hypoventilation, leading to mismatch in ventilation/perfusion, hence hypoxia (Luce, 1980; Bedell *et al*, 1958; Farebrother *et al*, 1974; Holley *et al*, 1967). Sleep apnea is common in overweight subjects and has been related to large waist circumference (Grunstein *et al*, 1993; Wilcox *et al*, 1994), and weight loss improves this symptom (Surratt *et al*, 1992).

Although most overweight people are aware of breathlessness on exertion (Dempsey *et al*, 1966), the nature of the relationships between overweight, particularly with increased waist to hip ratio or increased waist circumference, and symptoms of respiratory insufficiency are not well established. The present study aimed to examine the associations between respiratory symptoms and high body mass index, high waist to hip ratio, or large waist circumference.

METHODS

Subjects

Men ($n = 5887$) and women ($n = 7018$), aged 20-59 years were randomly recruited from three towns, Amsterdam, Maastricht and Doetinchem in the Netherlands from 1993 to 1995, in the ongoing MORGEN (Monitoring of Risk Factors and Health in The Netherlands) study undertaken as a public health surveillance to monitor chronic diseases, risk factors and their consequences. To obtain similar numbers of subjects at each age, the sample was stratified by sex and five year age group. The response rate to invitations was about 50%. The numbers of subjects in the present study represent those who attended the health centres for measurements including anthropometry. Those who did not attend the health centres or were of non-Dutch nationality were excluded from analyses.

Respiratory symptoms were obtained from a selection of questions that were used in the European Respiratory Health survey (Burney *et al*, 1994). Eight symptoms were selected for analysis including wheezing in the past twelve months when not having a cold, coughing daily (day or night) for a total of 3 or more months per year, bringing up phlegm daily (day or night) for a total of 3 or more months per year, chronic productive cough (periods of cough with phlegm in the past 3 years for at least 3 weeks per year, being woken up by shortness of breath during past 12 months, shortness of breath when walking uphill/stairs, and shortness of breath when walking at normal pace with people of the same age.

Anthropometric measurements were made according to the World Health Organisation (1995) recommendations by paramedical personnel. Subjects wore light clothes during measurements of body weight to the nearest 100g using calibrated scales, height in bare feet to the nearest mm, waist circumference in duplicate at the level between the lowest rib margin and iliac crest, and hip circumference at the widest trochanters to the nearest mm. Waist to hip circumferential ratio was computed, and body mass index was calculated as weight (kg) divided by height squared (m^2).

Statistical methods

All statistical analyses were performed using SAS version 6.1 (Cary, USA). Respiratory symptoms were dichotomous. Tertiles for anthropometric variables were created to define the levels of overweight (body mass index), central fat distribution (waist to hip ratio), and waist circumference was examined since waist reflects both overweight and fat distribution (**Chapter 4.1**; Lean *et al*, 1995). The age adjusted prevalence of respiratory symptoms was calculated for subjects in tertiles of anthropometry, using analysis of variance, adding age as a covariate. Logistic regression analysis, unadjusted, adjusted for age, and adjusted for age and lifestyle factors, was performed to estimate the relative risk (odds ratios and 95% confidence intervals) of respiratory symptoms in different tertiles of anthropometry. Separate analysis in different groups of smoking status was performed, since smoking is a strong determinant of respiratory symptoms, thus eliminating possible residual confounding effects of smoking. For convenience of presentation, only odds ratios with adjustments for age and lifestyle factors were tabulated.

Males and females were analysed separately, potential confounding factors considered dummy variables of age: divided into 10 year groups (20-29 year group as reference), smoking: non-smokers, ex-smokers, and current smokers (non-smokers as reference), educational level: secondary education or lower (educational level 1), vocational or higher secondary education (educational level 2), and higher vocational education or university education (educational level 3) (educational level 1 as reference), leisure activity: non participants, and participants in leisure sport (non-participant as reference).

Three types of subjects with chronic productive cough, wheeze, and smokers were considered in a separate group to assess the possible aggravation of shortness of breath from obesity. Those who never smoked and who did not have chronic productive cough or wheeze were considered separately to assess the impact of overweight or abdominal fat on shortness of breath in people with normal lungs.

RESULTS

Subject characteristics are shown in **Table 5.4.1**. In general, the age adjusted prevalence of subjects with respiratory symptoms significantly increased with increasing anthropometric measurements, and more strongly in women (**Tables 5.4.2a** & **b**). In men (**Table 5.4.2a**), non-linear relationships between anthropometric measurements and wheezing when not having a cold and chronic productive cough, and an inverse relationship between body mass index and bringing up phlegm were observed.

Age and lifestyle factors adjusted odds ratios to estimate relative risks of having respiratory symptoms (**Table 5.4.3**) showed that those who had large waist circumference (tertile 3) were associated with 2 to 2.5 times the risk of having shortness of breath when walking uphill/stairs, about 2 times in men and 2.5 to 3.5 in women the risk of having shortness of breath when walking at normal pace with others of their age. In women only, the risks of wheezing without a cold, of being woken up by shortness of breath and chronic productive cough, were all increased by about 1.5 times in tertile 3 compared to those with low (tertile 1). Compared to men with waist circumference in tertile 1, odds ratio for chronic productive cough in men with waist in tertile 2 were significantly less than 1, *i.e.* chronic productive cough was associated with low waist circumference. Compared to the lowest tertile, the odds ratios for these respiratory symptoms in subjects with high body mass index or with high waist to hip ratio (results not shown) were similar (mostly to within 0.1 unit of odds ratios) to the odds ratios presented in **Table 5.4.3** for waist circumference.

Figures 5.4.1a & b show that within separate groups of non-smokers and smokers, the prevalence of those with shortness of breath when walking uphill or upstairs increased with increasing waist circumference, and significantly (P <0.001) higher in smokers for each level of waist circumference. After excluding subjects with underlying lung disease (wheezing and chronic productive cough) in non-smokers (**Tables 5.4.4a** & **b**), the risk for shortness of breath continued to persist in those with large waist circumference, high body mass index, or high waist to hip ratio.

DISCUSSION

The present study shows that the age adjusted prevalence of respiratory symptoms increased with increasing waist circumference, body mass index and waist to hip ratio. Compared to the lowest tertile those with waist circumference, body mass index, or waist to hip ratio in tertile 3 were at 2-3 times more likely to have shortness of breath when walking uphill or walking with their peers (same age) at normal pace. Women with high measures of adiposity also had significant risks of other respiratory symptoms such as wheezing, coughing, and being woken up by attack of shortness of breath, the latter could indicate sleep apneas or coronary disease.

Shortness of breath is usually taken to indicate respiratory disease, but can in fact be a symptom of overweight *per se, i.e.* excessive body mass and central fat distribution, as demonstrated in subjects who did not have chronic productive cough or wheeze and those who have never smoked (**Tables 5.4.4a** & **b**). One of the most distinctive features of overweight is poor physical fitness. These persons are less able to perform physical work effectively. The excessive body mass requires increased effort by overweight subjects for movement (Dempsey *et al*, 1966). Subject to exercise testing, overweight subjects demonstrate increased O_2 consumption and CO_2 production, leading to increased ventilation (Dempsey *et al*, 1966). Thus, these subjects are more likely to be out of breath more easily than leaner subjects for a given work load.

Data from the present study show subjects with chronic productive cough were most prevalent both in the highest and in the lowest tertile of body mass index and waist circumference. Smoking was more prevalent in those with productive cough (about 50% in both sexes) than other subjects (<35%) making the analysis more complicated. It is known that smoking is related to relatively low body mass index and low waist circumference (accompanying paper), but the risk of having shortness of breath in smokers with a waist in lower tertiles was similar to that in non-smokers with the largest waist circumference (**Figures 5.4.1a** & **b**). Within the group of smokers and those with symptoms of lung disease, shortness of breath continued to increase in those with higher body mass, high waist to hip ratio or larger waist circumference (**Tables 5.4.4a & b**). There was no evidence for residual confounding effects of smoking when separate analysis were made for subjects in different smoking status (data not shown). Subjects in the advanced stage of chronic productive cough (chronic bronchitis) may be prone to weight loss (Mitchell and Filley, 1964; Vandenbergh *et al*, 1967). Different types of patients of different anthropometric characteristics, *e.g.* the overweight, hypoxic 'blue bloaters' and the underweight, emphysematous 'pink puffers', exist in those with chronic bronchitis (Filley *et al*, 1968) may explain these differences. In patients with established respiratory disease, a vicious cycle with limited physical activity contributes to weight gain, and increased frequency of acute infective exacerbation. Cachexia is also common in patients with severe lung disease (Mitchell *et al*, 1964; Wilson *et al*, 1989), and malnutrition or negative energy balance in this group aggravates respiratory distress through wasting of respiratory muscles (Vandenbergh *et al*, 1967; Donahoe *et al*, 1989; Openbrier *et al*, 1983; Thurlbeck, 1978).

The relationship between body weight and subjects with chronic productive cough, a diagnosis for chronic bronchitis, is less clear than that with emphysema, which associates with severe weight loss (Filley *et al*, 1968; Donahoe *et al*, 1989; Green and Muers, 1992). Openbrier *et al* (1983) found all four bronchitic patients in their study had body weight above standard weight, whereas Steele and Heard observed the mean weight of 12 patients was lower than the control group (Steele and Heard, 1973).

CONCLUSIONS

Overweight men and women, and those with central fat distribution or increased waist circumference are all at increased risk of respiratory symptoms, particularly shortness of breath when performing basic activities such as climbing stairs or walking at normal pace with people of their age. These symptoms are aggravated by smoking and by underlying lung disease. Preventing weight gain and healthy lifestyle should be recommended to decrease the risk of these symptoms associated with adiposity.

Table 5.4.1. Characteristics of 5881 men and 7018 women.

	Men			Women		
	Mean	SD	Range	Mean	SD	Range
Age (years)	42.9	10.7	20.3-60.0	42.2	11.0	20.2-59.9
Weight (kg)	82.0	12.0	44.4-157.0	68.5	11.5	36.6-153.0
Height (cm)	178.4	7.3	152.0-210.0	165.7	6.7	134.5-190.0
Body mass index (kg/m^2)	25.8	3.5	15.7-50.1	25.0	4.2	14.9-58.3
Waist circumference (cm)	92.3	10.8	64.0-155.0	81.0	11.1	56.5-150.0
Hip circumference (cm)	101.8	6.6	69.0-150.0	102.2	8.4	76.4-165.0
Waist to hip ratio	0.905	0.072	0.621-1.369	0.791	0.070	0.567-1.302

Table 2a. Age adjusted prevalence of respiratory symptoms in tertiles of anthropometry in 5887 men.

Men	Body mass index tertiles				Waist to hip ratio tertiles				Waist circumference tertiles			
	1	2	3		1	2	3		1	2	3	
	%	%	%	*F*†	%	%	%	*F*†	%	%	%	*F*†
n	*1962*	*1963*	*1962*		*1962*	*1962*	*1963*		*1898*	*1946*	*2043*	
Wheezing when not having a cold	8.7	9.0	10.1	0.88	8.4	8.0	11.3	4.70***	9.0	7.9	10.8	3.29*
Coughing ≥3 months/year	8.7	7.2	7.2	2.14	6.2	8.1	8.8	3.56*	7.2	7.5	8.4	1.50
Bringing up phlegm ≥3 months/year	7.6	6.2	6.6	3.38**	6.3	6.7	7.6	3.59*	6.9	6.3	7.2	3.31*
Chronic productive cough‡	19.3	16.6	17.5	2.32	17.4	17.2	18.8	1.28	19.2	16.0	18.3	2.92*
Woken up by shortness of breath	4.8	4.8	5.4	2.62*	4.4	4.9	5.7	3.22*	4.8	4.2	6.0	4.65**
Breathless when walking uphill/stairs	12.8	12.2	23.1	64.3***	10.3	12.7	25.1	82.2***	11.5	11.7	24.4	79.3***
Breathless when walking with others	3.7	3.4	6.6	22.4***	3.3	2.8	7.5	31.7***	3.6	2.8	7.1	28.9***

†Analysis of variance for the difference in prevalence of respiratory symptom between tertiles of body mass index, waist to hip ratio and waist circumference respectively;

‡coughing up phlegm ≥3 weeks/year in the past three years.

Table 2b. Age adjusted prevalence of respiratory symptoms in tertiles of anthropometry in 7018 women.

Women	Body mass index tertiles				Waist to hip ratio tertiles				Waist circumference tertiles			
	1	2	3		1	2	3		1	2	3	
	%	%	%	*F*†	%	%	%	*F*†	%	%	%	*F*†
n	*2340*	*2340*	*2338*		*2338*	*2340*	*2340*		*2293*	*2315*	*2410*	
Wheezing when not having a cold	7.6	7.8	9.9	6.19***	7.1	7.4	10.7	10.2***	7.1	7.3	10.8	11.1***
Coughing ≥3 months/year	6.6	6.8	9.1	8.88***	5.5	7.7	9.4	12.1***	6.3	6.8	9.4	10.4***
Bringing up phlegm ≥3 months/year	4.8	4.4	6.0	6.69***	4.0	4.8	6.1	6.84***	4.3	4.6	5.9	5.64***
Chronic productive cough‡	19.3	18.0	18.7	1.93	17.7	18.4	19.7	2.44	18.5	18.1	19.3	1.91
Woken up by shortness of breath	4.5	5.7	8.1	8.92***	4.7	5.6	8.0	7.49***	4.5	5.2	8.5	11.8***
Breathless when walking uphill/stairs	17.6	21.5	34.8	97.5***	18.1	23.2	32.7	72.0***	19.7	22.2	34.6	96.5***
Breathless when walking with others	4.0	6.1	13.1	61.9***	4.6	7.2	11.5	37.9***	4.1	6.5	12.4	51.2***

†Analysis of variance for the difference in prevalence of respiratory symptom between tertiles of body mass index, waist to hip ratio and waist circumference respectively;

‡coughing up phlegm ≥3 weeks/year in the past three years.

Table 5.4.3. Odds ratios of respiratory symptoms in different tertiles of waist circumference, adjusted for age, smoking, physical activity, and education.

	Waist circumference				
	Tertile 1	Tertile 2		Tertile 3	
	Odds ratio	Odds ratio	95% CI	Odds ratio	95% CI
MEN (n = 5887)					
Wheezing when not having a cold†	1.00	0.90	0.71, 1.15	1.21	0.96, 1.54
Coughing for ≥3 months/year‡	1.00	1.13	0.87, 1.47	1.19	0.91, 1.55
Bring up phlegm ≥3 months/year‡	1.00	0.96	0.73, 1.26	1.04	0.79, 1.37
Chronic productive cough§	1.00	0.83*	0.70, 0.99	0.96	0.80, 1.15
Woken by shortness of breath	1.00	0.87	0.63, 1.20	1.18	0.86, 1.62
Shortness of breath - uphill/stairs§	1.00	1.11	0.89, 1.37	2.41***	1.97, 2.96
Shortness of breath - normal pace¶	1.00	0.81	0.55, 1.20	1.80***	1.27, 2.54
WOMEN (n = 7018)					
Wheezing when not having a cold†	1.00	1.06	0.84, 1.34	1.64***	1.31, 2.07
Coughing for ≥3 months/year‡	1.00	1.10	0.86, 1.41	1.55***	1.21, 1.98
Bring up phlegm ≥3 months/year‡	1.00	1.08	0.81, 1.45	1.39*	1.04, 1.86
Chronic productive cough§	1.00	1.01	0.86, 1.17	1.13	0.96, 1.33
Woken by shortness of breath	1.00	1.13	0.86, 1.49	1.82***	1.40, 2.38
Shortness of breath - uphill/stairs§	1.00	1.45***	1.24, 1.69	2.55***	2.19, 2.98
Shortness of breath - normal pace¶	1.00	1.64***	1.24, 2.17	2.94***	2.25, 3.84

***P <0.001, **P <0.01, *P <0.05; CI = confidence interval; †in the past 12 months; ‡in the past 3 years; §coughing with phlegm ≥3 weeks/year in the past 3 years; §when walking uphill/stairs ¶when walking at normal pace with others of the same age.

Table 4a. Age, physical activity, and education adjusted odds ratios of shortness of breath when walking uphill or stairs in different tertiles of waist circumference, body mass index and waist to hip ratio for male non-smokers and without symptoms, and smokers and those with symptoms of underlying lung disease.

Men	*n*	Proportion of men with shortness of breath (%)	Tertile 1	Tertile 2		Tertile 3	
			Odds ratio	Odds ratio	95% CI	Odds ratio	95% CI
			Waist circumference				
Non-smokers and without symptoms†	1496	6.79	1.00	1.79	0.88, 3.67	5.42***	2.77, 10.61
Smokers and with symptoms†	2804	24.25	1.00	1.07	0.84, 1.38	2.05***	1.62, 2.60
			Body mass index				
Non-smokers and without symptoms†	1490	6.79	1.00	1.62	0.83, 3.18	4.23***	2.26, 7.94
Smokers and with symptoms†	2804	24.25	1.00	1.03	0.82, 1.31	1.87***	1.50, 2.34
			Waist to hip ratio				
Non-smokers and without symptoms†	1496	6.79	1.00	2.70**	1.32, 5.54	7.36***	3.16, 15.00
Smokers and with symptoms†	2804	24.25	1.00	1.11	0.86, 1.43	2.12***	1.64, 2.73

***P <0.001, **P <0.01, *P <0.05; †symptoms = wheezing or chronic productive cough (coughing with phlegm ≥3 weeks/year in the past 3 years).

Table 4b. Age, physical activity, and education adjusted odds ratios of shortness of breath when walking uphill or stairs in different tertiles of waist circumference, body mass index and waist to hip ratio for female non-smokers and without symptoms, and smokers and those with symptoms of underlying lung disease.

Women	*n*	Proportion of women with shortness of breath (%)	Tertile 1	Tertile 2		Tertile 3	
			Odds ratio	Odds ratio	95% CI	Odds ratio	95% CI
			Waist circumference				
Non-smokers and without symptoms†	2087	4.55	1.00	1.98***	1.36, 2.86	3.23***	2.23, 4.67
Smokers and with symptoms†	3381	11.12	1.00	1.38***	1.14, 1.68	2.41***	1.98, 2.93
			Body mass index				
Non-smokers and without symptom†	2087	4.55	1.00	1.82**	1.24, 2.66	3.98***	2.76, 5.75
Smokers and with symptoms†	3381	11.12	1.00	1.28**	1.06, 1.54	2.30***	1.90, 2.79
			Waist to hip ratio				
Non-smokers and without symptom†	2087	4.55	1.00	1.04	0.72, 1.51	1.66***	1.16, 2.38
Smokers and with symptoms†	3381	11.12	1.00	1.55***	1.10, 2.17	1.98***	1.40, 2.80

***P <0.001, **P <0.01, *P <0.05; †symptoms = wheezing or chronic productive cough (coughing with phlegm ≥3 weeks/year in the past 3 years).

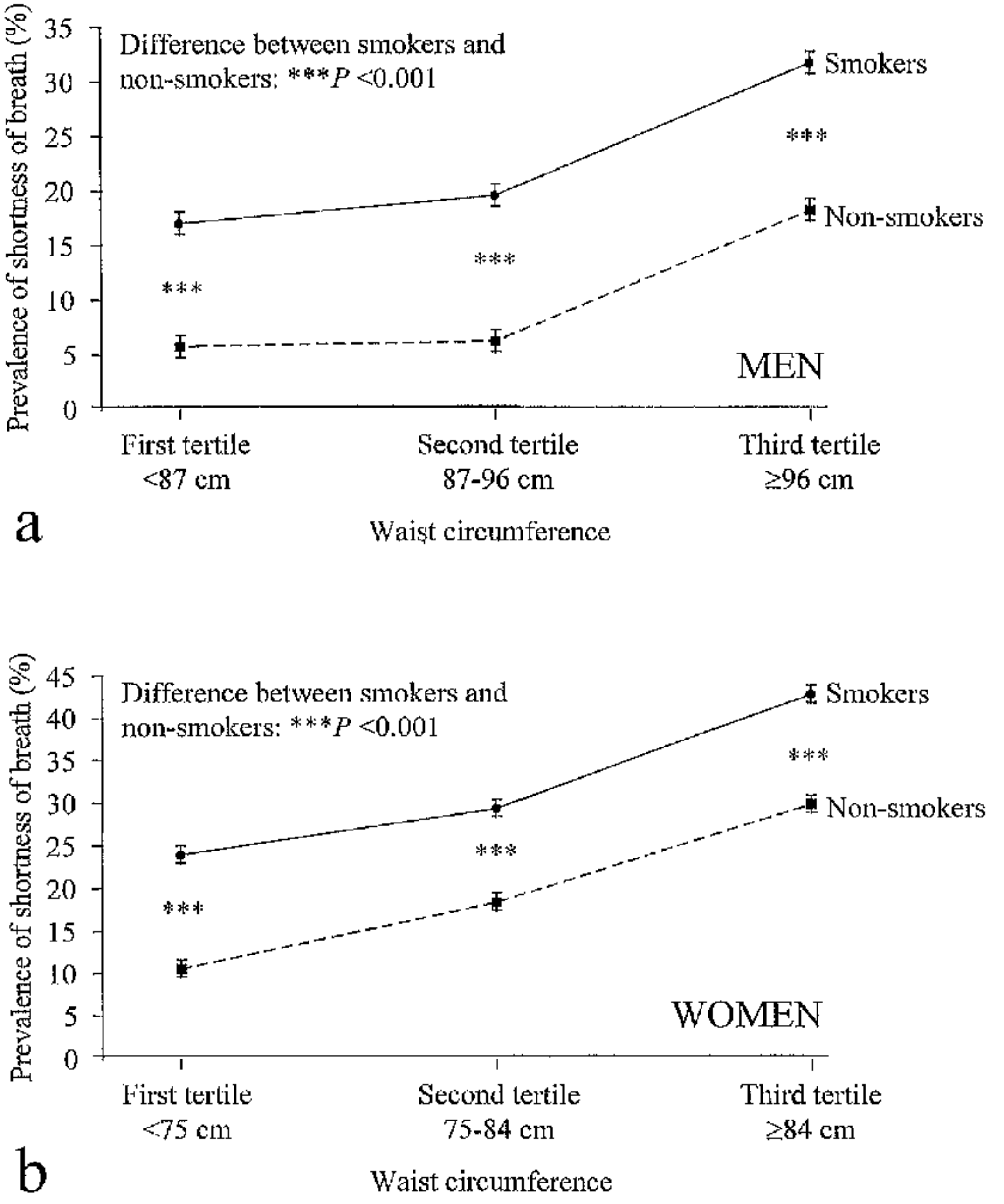


Figure 5.4.1 . Age adjusted prevalence (SE) of shortness of breath when walking uphill/stairs in different tertiles of waist in men (a) and women (b) who never smoked (dashed line) and those who were current smokers (solid line).

— 5.5 —

ASSOCIATIONS OF STATURE, BODY MASS AND FAT DISTRIBUTION WITH NON-INSULIN-DEPENDENT DIABETES MELLITUS

This section has been submitted for publication as

Han TS, Feskens EJM, Lean MEJ, Seidell JC. Associations of stature, body mass and fat distribution with Type 2 (non-insulin-dependent) diabetes mellitus. (submitted)

Collaboration with MORGEN project

ABSTRACT

Objective: To establish the associations of stature, body mass index, waist to hip ratio and waist circumference with Type 2 (non-insulin dependent) diabetes mellitus.

Setting: Random sample of 5887 men and 7018 women aged 20-59 years, in a cross-sectional study set in The Netherlands.

Results: The crude prevalence of Type 2 diabetes (overall 1.58% in men, 0.94% in women) was significantly (P <0.01) higher in shorter subjects and those with high body mass index, high waist to hip ratio and larger waist circumference. Compared to the tallest tertile, age adjusted odds ratios (95% confidence intervals) for Type 2 diabetes were 5.1 (2.0 to 13.3) in men and 2.1 (1.1 to 4.0) in women whose height was in the shortest tertile. Compared to the lowest tertile, the age adjusted odds ratios for Type 2 diabetes were 19.7 (4.7 to 83.5) in men and 6.3 (2.4 to 16.4) in women with waist to hip ratio in the highest tertile, 4.4 (2.2 to 9.0) in men and 2.5 (1.2 to 4.9) in women with body mass index in the highest tertile, and 5.2 (2.2 to 12.3) in men and 3.2 (1.4 to 7.0) in women with waist circumference in the highest tertile. Additional adjustments for cigarette smoking, alcohol consumption, physical activity and educational level slightly reduced the strength of these associations, and odds ratio for shortest women became non-significant.

Conclusions: Although in longitudinal studies waist is a powerful predictor of diabetes incidence, Type 2 diabetes in a cross-sectional survey is associated with shortness in stature, as well as large waist circumference and high body mass index, and particularly strongly with high waist to hip ratio, suggesting that the development of Type 2 diabetes may modify hip circumference independently of body fat.

Keywords: Body constituent, early growth, health promotion, height, skeletal muscle

INTRODUCTION

Type 2 (non-insulin-dependent) diabetes mellitus is a disease of nutrient storage and metabolism which associates with several other metabolic aberrations such as hyperlipidaemia and hypertension. Increased visceral fat mass is a major characterising feature, possibly aetiologically important through increased fatty acid release into the portal system (Björntorp, 1991; Björntorp, 1996) but these mechanisms have not been elucidated. It is well established that the measure of waist to hip ratio strongly relates with the development of Type 2 diabetes (Hartz *et al*, 1983; Ohlson *et al*, 1985; Chan *et al*, 1994). This association has usually been interpreted as the result of central fat distribution, central obesity, upper body obesity, or truncal fatness. However, waist circumference is more highly predictive of intra-abdominal fat than waist to hip ratio (Seidell *et al*, 1988; Pouliot *et al*, 1994).

Type 2 diabetes has also been suggested as a consequence of developmental failure of vital organs, such as the pancreas and the liver, particularly in those who were exposed to poor nutritional conditions at a critical stage of fetal development (Barker, 1994). It is well established that short stature can reflect underdevelopment during the critical growth periods (Floud *et al*, 1990).

The present study aimed to assess the prevalence and relative risks of Type 2 diabetes in relation to body stature and to body fatness and fat distribution.

METHODS

Subjects

Dutch men (n = 5887) and women (n = 7018) aged 20-59, recruited into the ongoing MORGEN (Monitoring of Risk Factors and Health in The Netherlands) study in the 1993 to 1995 cohorts from Amsterdam, Maastricht, and Doetinchem. To obtain similar numbers of subjects at each age, the sample was stratified by sex and five year age group.

Anthropometry

Anthropometric measurements were made according to the World Health Organisation recommendations (WHO, 1989) by trained field scientists. Subjects were wearing light clothes during measurements of body weight to the nearest 100g using calibrated scales, height without shoes to the nearest mm, waist circumference in duplicate at the level between the lowest rib margin and iliac crest, and hip circumference at the widest trochanters to the nearest mm. Waist to hip circumferential ratio was computed, and body mass index was calculated as weight (kg) divided by height squared (m^2).

Definition of non-insulin dependent diabetes mellitus (Type 2 diabetes)

Subjects with known diagnosed Type 2 diabetes or with newly diagnosed Type 2 diabetes from random blood glucose concentration of ≥11.1 mmol/l (WHO, 1985) in the present survey, were selected as having the disease. Five men and nine women treated with insulin were excluded. Blood glucose was measured by World Health Organisation standardised laboratory at the Academic Dijkzig Hospital of the Erasmus University in Rotterdam.

Statistical methods

Statistical analyses were performed using SAS version 6.1 (Cary, USA). Tertiles were created for height, body mass index, waist to hip ratio and waist circumference. The prevalence of Type 2 diabetes were determined for subjects in each tertile of anthropometry, using cross tabulation with Chi square statistic. Logistic regression analysis for unadjusted and adjusted for age and lifestyle factors was performed to estimate the relative risks (odds ratios and 95% confidence intervals) of Type 2 diabetes in tertiles of height, body mass index, waist to hip ratio and waist circumference. We have already demonstrated the lack of significant correlation between waist and height in these subjects for the 1993-1994 cohorts (**Chapter 4.3**; Han *et al*, 1996b; Han *et al*, 1997c). Thus waist to height ratio was not created. Height was entered in multivariate logistic regression analysis as independent variable in the associations of Type 2 diabetes with waist or with waist to hip ratio.

Confounding factors

Males and females were analysed separately. Dummy variables were created for the following confounding factors; age: stratified by 10 year age categories, smoking: non-smokers, ex-smokers, and current smokers, alcohol: non-drinkers, occasional drinkers (<1 glass per day), moderate drinkers (1 to 2 glasses per day), and heavy drinkers (≥3 glasses per day), educational level: secondary education or lower (educational level 1), vocational or higher secondary education (educational level 2), and higher vocational education or university education (educational level 3), physical activity: non participants, and participants in leisure sport.

RESULTS

Table 5.5.1 shows subjects with known Type 2 diabetes and those with newly diagnosed Type 2 diabetes were similar in age. It is clear that both of these groups of subjects with metabolic complications were older, shorter, heavier, and they had higher body mass index, higher waist to hip ratio and larger waist circumference than subjects without Type 2 diabetes. Mean (SD) duration of known Type 2 diabetes was 5.5 (6.7) years in men and 7.6 (9.1) in women, and age of diagnosis was 45.6 (9.7) in men and 43.3 (9.1) in women.

Tables 5.5.2a & b show that the unadjusted prevalence of Type 2 diabetes was relatively high in categories of short stature, higher body mass index, higher waist to hip ratio and larger waist circumference. In both sexes, compared to lowest tertile (highest tertile in the case of height) the age adjusted odds ratios for Type 2 diabetes were significantly higher in the shortest tertile of height, third tertile of waist to hip ratio, body mass index and waist circumference (**Figure 5.5.1**). **Table 5.5.3** shows that after additional adjustment for cigarette smoking, alcohol consumption, educational level and physical activity, the strength of the associations was slightly reduced, and the relationship between Type 2 diabetes and height in women became non-significant.

Adjustments for height and waist to hip ratio, or height and waist circumference had no substantial changes to odds ratios (within 0.1 unit) of either height, waist to hip ratio or waist circumference. Excluding the 30 men and 15 women who were newly diagnosed with Type 2 diabetes (random blood glucose ≥11.1 mmol/l), did not change the results considerably (within 0.1 unit of odds ratios: results not presented).

DISCUSSION

The present study confirmed previous findings for the associations between high waist to hip ratio, high body mass index, and large waist circumference with Type 2 diabetes, hyperglycaemia and insulin resistance (Björntorp, 1991; Björntorp, 1996; Johnson *et al*, 1992; Kohrt *et al*, 1993; Weidner *et al*, 1995). After age adjustment, shorter men were 5 times and shorter women were 2 times more likely to have Type 2 diabetes compared to taller subjects. Shorter men remained to associate significantly with Type 2 diabetes even additional after adjustments for educational level, smoking and physical activity level, suggesting that this association was independent of social class and lifestyle habits. Our findings support previous studies of Brown *et al* (1991) who have observed a negative correlations between glucose tolerance and height, and that of Mooy *et al* (1995) who have shown that shortness of stature was a significant determinant of glucose intolerance. Since both short stature (Floud *et al*, 1990) and Type 2 diabetes (Barker, 1994) reflect reduced development during the critical periods of growth, these factors may be linked in the aetiology of Type 2 diabetes. Early growth underdevelopment, reflected by low birth weight, has been shown to associate with high waist to hip ratio in men (Alvarsson *et al*, 1994) and increased waist circumference in women (Jarrett and Fitzgerald, 1992). All these adverse anthropometric measures are characteristics of poor health. Barker *et al* (1990) have shown that shorter populations have higher risks of mortality from cardiovascular disease, chronic bronchitis, and cancers in men and women. A study of diabetes in rural Tanzania has shown that the prevalence of impaired glucose tolerance, but not diabetes, tended to be higher in shorter men and shorter women (McKeigue, 1991). According to the thrifty phenotype hypothesis (Hales and Barker, 1992), the risk of diabetes for shorter subjects in the study of Swai *et al* (1992) would not be great, since rural Tanzanians were not be exposed to overnutrition.

Our observations indicate greater risk of Type 2 diabetes in shorter people, particularly men, even after adjusting for age, lifestyle factors and body fat distribution, and this would be in broad agreement with the findings of Barker's group (Law *et al*, 1992). A possible mechanism would be the alterations in mass of metabolically important tissues - particularly skeletal muscle. Indeed, high waist to hip ratio was most strongly related to Type 2 diabetes in the present study. If intra-abdominal fat were the only influence on development of Type 2 diabetes, then waist circumference alone should be at least as strongly associated with Type 2 diabetes as waist to hip ratio, since the waist reflects intra-abdominal fat (Seidell *et al*, 1988, Pouliot *et al*, 1994) (itself determined by total fatness and by fat distribution), whilst the hip circumference includes contributions from the bone structure of the pelvis, and the truncal muscles which make up one of the main organs for glucose metabolism and insulin action (DeFronzo, 1988). Our study (Seidell *et al*, 1997) of the same subjects, using residual analysis to dissociate the contributions of the waist and hip circumference to Type 2 diabetes, showed clearly that as well as large waist, a smaller hip circumference than expected from a given body mass index was importantly associated with Type 2 diabetes, these associations were independent of height. Hartz *et al* (1984) used discrimination analysis to adjust for relative weight, age and hips or waist found that waist circumference was positively and hip circumference was negatively associated with diabetes in women. It is possible that increased intra-abdominal fat precedes the development of Type 2 diabetes, and muscle atrophy follows afterwards, since insulin action and glucose clearance are related similarly (Carey *et al*, 1996) or more highly with waist circumference than with waist to hip ratio in non-diabetic subjects (Pouliot *et al* 1994; Weidner *et al*, 191995). This could explain the consistently different associations with Type 2 diabetes in longitudinal and cross-sectional studies. Ohlson *et al* (1985) have shown that waist circumference was at least as strong ($P = 0.0012$) as waist to hip ratio ($P = 0.0037$) in predicting the development of Type 2 diabetes over thirteen and a half years in men, even after body mass index was accounted for. A five year follow up study in men (Chan *et al*, 1994) confirmed these findings showing that with reference to those in the lowest quintile, prediction of Type 2 diabetes development in men with waist circumference in the fifth quintile (age adjusted relative risk 12) was more strongly than those with waist to hip ratio in the fifth quintile (age adjusted relative risk 4). Lemieux *et al* (1996a) have found that seven year changes in indices of glucose-insulin homeostasis were related to changes in visceral fat and waist circumference, but not to waist to hip ratio in non-diabetic women. If muscle loss leads to lower hips when Type 2 diabetes develops, then only waist would predict the development of Type 2 diabetes, whilst waist to hip ratio would be a better marker of existing Type 2 diabetes. This would require prospective study.

Prentice and Jebb (1995) have suggested that physical inactivity may be an important factor contributing factor to the rising prevalence of overweight (Gregory *et al*, 1990; Bennett *et al*, 1995) since average energy intake in Britain has apparently declined. The prevalences of overweight (Knowler *et al* ,1981) and associated Type 2 diabetes in Pima Indians are amongst the highest in the world (Knowler *et al*, 1978), and Fontvieille *et al* (1993) have shown that Pima Indian children are less physically active than Caucasian children. In a study of 24 healthy men, Seidell *et al* (1989a) have shown that those with increased waist to hip ratio were associated with relatively less thigh muscle, raised insulin and decreased muscle endurance. These findings point towards an important role of peripheral muscle in the association between altered body morphology and related diseases such as Type 2 diabetes. The link of diabetes with reduced oxidative muscle fibres is established (Lillioja *et al*, 1987). Exercise can prevent muscle atrophy or increase muscle mass, and alter muscle morphology towards higher oxidative capacity by increased vascularisation (Åstrand and Rodahl, 1986), increased oxidative enzymes and mitochondrial density, upregulation of insulin receptors and increased insulin sensitivity (Devlin *et al*, 1992). It has been suggested that regular exercise may prevent the development of Type 2 diabetes (Helmrich *et al*, 1991). We have found that those who are physically inactive have a smaller hip circumference than expected for their given body mass index (**Chapter 5.1**).

CONCLUSIONS

Although in longitudinal studies waist is as least as powerful as waist to hip ratio in predicting diabetes incidence, Type 2 diabetes in a cross-sectional survey is associated with shortness in stature, large waist circumference and high body mass index, and particularly strong with high waist to hip ratio, suggesting that the development of Type 2 diabetes may modify hip circumference independently of body fat.

Table 5.5.1. Characteristics of subjects with known Type 2 diabetes, newly diagnosed Type 2 diabetes (random blood glucose concentration of ≥11.1 mmol/l), and other subjects.

	Known Type 2 diabetes		Newly diagnosed Type 2 diabetes		Other subjects	
	Mean	SE	Mean	SE	Mean	SE
MEN	*(n = 63)*		*(n = 30)*		*(n = 5794)*	
Age (years)	51.1	0.91	53.1	1.02	42.7	0.14
Weight (kg)	85.6	1.99	97.2	3.37	81.9	0.16
Height (cm)	173.1	0.83	176.4	1.36	178.5	0.10
Body mass index (kg/m^2)	28.5	0.56	31.2	0.95	25.7	0.05
Waist circumference (cm)	100.0	1.58	111.2	2.56	92.1	0.14
Hip circumference (cm)	102.1	1.09	109.4	2.31	101.7	0.09
Waist to hip ratio	0.977	0.007	1.017	0.012	0.904	0.001
Age (years)	50.8	1.03	51.8	2.13	42.1	0.13
Weight (kg)	79.3	2.28	71.9	4.29	68.4	0.14
WOMEN	*(n = 51)*		*(n = 15)*		*(n = 6952)*	
Height (cm)	162.9	0.83	159.7	1.53	165.7	0.08
Body mass index (kg/m^2)	29.9	0.88	28.2	1.66	24.9	0.05
Waist circumference (cm)	96.7	2.13	92.3	3.68	80.9	0.13
Hip circumference (cm)	108.5	1.82	103.5	3.41	102.2	0.10
Waist to hip ratio	0.891	0.013	0.891	0.018	0.790	0.001

Table 5.4.2a. Crude prevalence and age adjusted odds ratios for Type 2 diabetes in different tertiles of anthropometry, in 5887 men.

	Prevalence	Odds ratio	95% confidence interval
	$n = 93$†		
Body mass index tertile 1 (<24.1 kg/m^2)	0.46	1.00	
Body mass index tertile 2 (24.1-26.9 kg/m^2)	0.87	1.30	0.57, 2.94
Body mass index tertile 3 (≥26.9 kg/m^2)	3.41	4.40***	2.16, 8.95
χ^2‡	65***		
Waist to hip ratio tertile 1 (<0.872)	0.10	1.00	
Waist to hip ratio tertile 2 (0.872-0.936)	0.66	4.07	0.90, 18.52
Waist to hip ratio tertile 3 (≥0.936)	3.98	19.70***	4.65, 83.51
χ^2‡	111***		
Waist circumference tertile 1 (<86.9 cm)	0.32	1.00	
Waist circumference tertile 2 (87.0-95.9 cm)	0.98	1.89	0.75, 4.81
Waist circumference tertile 3 (≥96.0 cm)	3.33	5.22***	2.21, 12.34
χ^2‡	64***		
Height tertile 3 (≥181.5 cm)	0.60	1.00	
Height tertile 2 (175.0-181.3 cm)	1.64	3.19***	1.20, 8.49
Height tertile 1 (<174.8 cm)	2.61	5.13***	1.98, 13.26
χ^2‡	24***		

***P <0.001, **P <0.01, *P <0.05; †number of subjects with Type 2 diabetes; ‡difference in prevalences between tertiles.

Table 5.5.2b. Crude prevalence and age adjusted odds ratios for Type 2 diabetes in different tertiles of anthropometry, in 7018 women.

	Prevalence	Odds ratio	95% confidence interval
	$n = 66$†		
Body mass index tertile 1 (<22.8 kg/m^2)	0.51	1.00	
Body mass index tertile 2 (22.8-25.9 kg/m^2)	0.34	0.52	0.21, 1.32
Body mass index tertile 3 (≥25.9 kg/m^2)	2.01	2.47*	1.24, 4.90
χ^2‡	43***		
Waist to hip ratio tertile 1 (<0.756)	0.21	1.00	
Waist to hip ratio tertile 2 (0.756-0.815)	0.30	1.05	0.33, 3.38
Waist to hip ratio tertile 3 (≥0.815)	2.31	6.27***	2.40, 16.41
χ^2‡	71***		
Waist circumference tertile 1 (<75.0 cm)	0.35	1.00	
Waist circumference tertile 2 (75.0-84.0 cm)	0.39	0.78	0.28, 2.04
Waist circumference tertile 3 (≥84.0 cm)	2.03	3.16**	1.44, 6.96
χ^2‡	47***		
Height tertile 3 (≥168.5 cm)	0.49	1.00	
Height tertile 2 (1630-168.0 cm)	0.80	1.31	0.63, 2.74
Height tertile 1 (<162.5 cm)	1.55	2.07*	1.06, 4.04
χ^2‡	15**		

***P <0.001, **P <0.01, *P <0.05; †number of subjects with Type 2 diabetes; ‡difference in prevalences between tertiles.

Table 5.5.3. Odds ratios for Type 2 diabetes in different tertiles of anthropometry, adjusted for age, smoking, alcohol consumption, physical activity, and education, in 5887 men and 7018 women.

	Men (n = 93†)		Women (n = 66†)	
	Odds ratio	95% confidence interval	Odds ratio	95% confidence interval
Body mass index tertile 1	1.00		1.00	
Body mass index tertile 2	1.34	0.59, 3.06	0.52	0.21, 1.30
Body mass index tertile 3	4.07***	1.98, 8.35	2.07*	1.03, 4.19
Waist to hip ratio tertile 1	1.00		1.00	
Waist to hip ratio tertile 2	4.16	0.91, 19.00	0.98	0.31, 3.14
Waist to hip ratio tertile 3	18.36***	4.29, 78.49	5.31***	2.02, 13.96
Waist tertile 1	1.00		1.00	
Waist tertile 2	1.93	0.76, 4.94	0.75	0.28, 1.98
Waist tertile 3	4.92***	2.07, 11.70	2.67*	1.20, 5.91
Height tertile 3	1.00		1.00	
Height tertile 2	3.07*	1.70, 8.16	1.25	0.60, 2.62
Height tertile 1	4.42**	1.26, 11.51	1.62	0.82, 3.18

***P <0.001, **P <0.01, *P <0.05; †number of subjects with Type 2 diabetes.

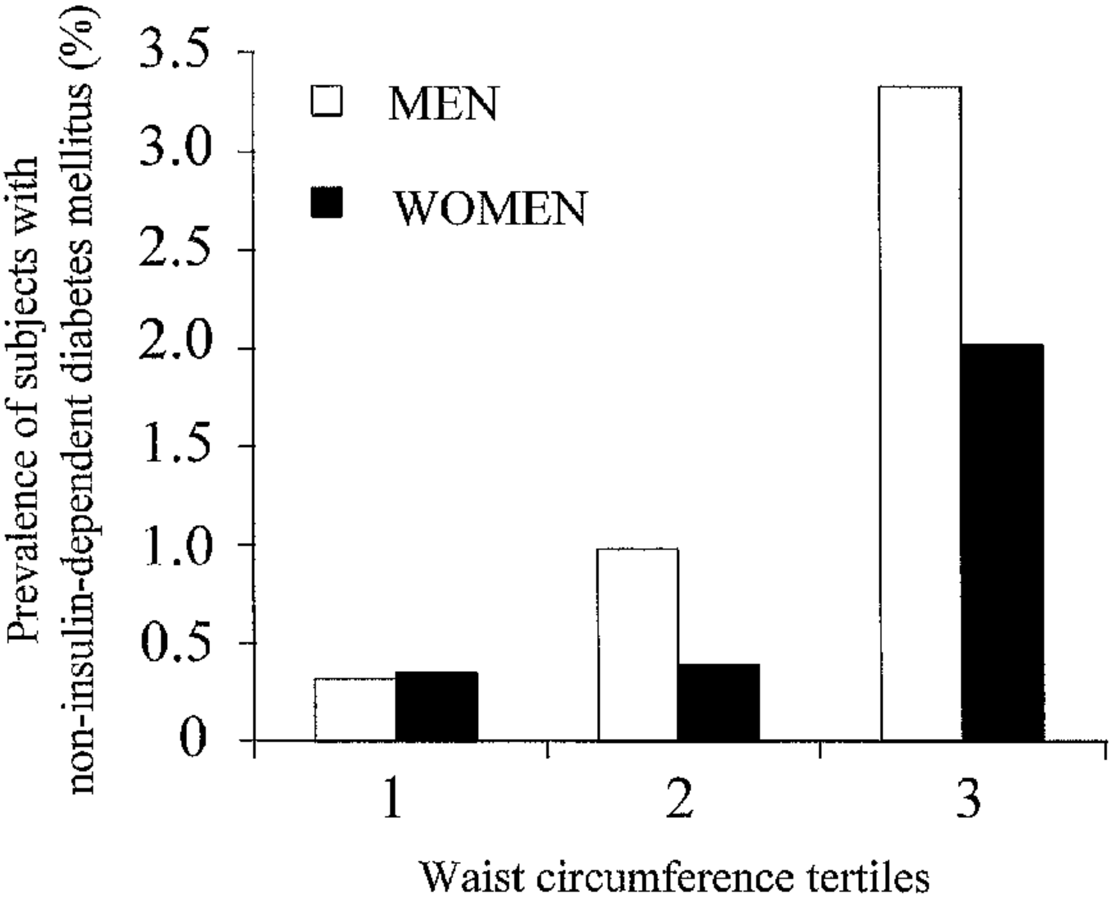


Figure 5.5.1. Prevalence of Type 2 diabetes mellitus in different tertiles of waist circumference (in men: tertile 1 <87.0 cm, tertile 2 = 87.0-96.0 cm, tertile 3 ≥96 cm; in women: tertile 1 <75.0 cm, tertile 2 = 75.0-84.0 cm, tertile 3 ≥84 cm).

— 5.6 —

QUALITY OF LIFE IN RELATION TO OVERWEIGHT AND FAT DISTRIBUTION

This section has been submitted for publication as

<u>**Han TS**</u>, Tijhuis MAR, Lean MEJ, Seidell JC. Quality of life in relation to overweight and body fat distribution. (submitted).

Collaboration with MORGEN project

ABSTRACT

Objective: To examine the quality of life in overweight subjects and those with high body mass index and adverse fat distribution.

Design: Cross-sectional study.

Setting: Monitoring Risk Factors and Health in The Netherlands (MORGEN) project.

Subjects: 1885 men and 2156 women aged 20-59 years, randomly sampled from the civil registries of Amsterdam, Maastricht and Doetinchem in 1995.

Main outcome measures: Measures of quality of life using SF-36 questionnaire.

Results: Compared to those in the lowest tertile, subjects with largest waist circumference were 1.8 times (95% confidence interval 1.3 to 2.4) in men and 2.2 times (1.7 to 2.9) in women more likely to have difficulties bending, kneeling or stooping, 2.2 times (1.4 to 3.7) in men and 1.7 (1.2 to 2.6) in women to have difficulties in walking several blocks, and 1.3 times (1.0 to 1.9) in men and 1.5 times (1.1 to 1.9) in women to have difficulties in lifting or carrying groceries. Anthropometric measures were less strongly associated with items from other health concepts concerning social functioning, role limitations due to physical problems or due to emotional problems, mental health, vitality, pain, or health change in one year. Quality of life measures related to body mass index and waist to hip ratio similarly to waist circumference.

Conclusions: People who have large waist circumference, high body mass index or high waist to hip ratio are more likely to have impaired quality of life, with poor self rated health, and limitations in the basic activities of daily living.

Keywords: epidemiology, health promotion, obesity, subjective health.

INTRODUCTION

In Western countries, 10-20% of men and women have a body mass index (BMI) above 30 kg/m^2 and figures have been increasing (Bennett *et al*, 1990; Kuczmarski *et al*, 1994; Seidell, 1995a). Although overweight and central fat distribution are associated with increased risks of chronic diseases such as diabetes (Ohlson *et al*, 1985), cardiovascular diseases (Lapidus *et al*, 1984; Larsson *et al*, 1984), cancers (den Tonkelaar *et al*, 1995; Giovannucci *et al*, 1995), and premature death (Manson *et al*, 1995; Simopoulos and van Itallie, 1984), it is surprising that the quality of life in overweight subjects is less well documented.

Early studies have indicated that overweight subjects are more likely to have poorer physical functioning status, a measure of quality of life (Stewart *et al*, 1983). With advancing age, overweight persons are more likely to develop serious limitations in performing basic daily activities (Launer *et al*, 1994). These persons impose an enormous burden on health care resources (Seidell, 1995b; Colditz, 1992). Poor physical function and quality of life attributable to overweight is important in terms of public health, and should be addressed by preventive measures, and promotion of healthy living. The quality of life in subjects with adverse fat distribution, i.e. large waist circumference and high waist to hip ratio (WHR), to our knowledge, has not been reported in the literature. The present study examined the quality of life in overweight subjects, and those with central fat distribution and large waist circumference.

METHODS

Subjects

1885 men and 2156 women aged 20-59 were recruited randomly from civil registrics for the ongoing MORGEN (Monitoring Risk Factors and Health in The Netherlands) project 1995 cohort, from Amsterdam, Maastricht, and Doetinchem. To obtain similar numbers of subjects at each age, the sample was stratified by sex and five year age group (Smit *et al*, 1994). The response rate to invitations was about 50%.

Anthropometry

All anthropometric measurements were made according to the World Health Organisation recommendations (1989) by trained paramedic personnel. Subjects wore light clothes during measurements of body weight to the nearest 100g using calibrated scales, height in bare feet to the nearest mm, waist circumference in duplicate at the level between the lowest rib margin and iliac crest, and hip circumference at the widest trochanters to the nearest mm. Waist to hip circumferential ratio was computed, and BMI was calculated as weight (kg) divided by height squared (m^2).

Quality of life

Nine 'health concepts' were calculated from thirty-six items rated by subjects using the standardised RAND-36 questionnaire, Dutch version (van der Zee and Sanderman, 1995), which was adapted from the standardised SF-36 Health Survey (Medical Outcomes Trust, 1994). These health concepts comprised measures of functioning - the ability to perform daily tasks and activities, and measures of well being - subjective internal states including how people feel physically and emotionally and how they think and feel about their health (Stewart *et al*, 1994). The nine health concepts were physical functioning, role functioning limitations due to poor physical health, bodily pain, general health, vitality, social functioning, role functioning limitations due to poor emotional health, mental health, and health transition in one year.

Lifestyle and demographic factors as confounding factors

Dummy variables (**Appendix 5.6.1**) for possible confounding factors were created to adjust for the associations between adiposity and health concepts and individual items.

Statistical methods

Statistical analyses were performed using SAS version 6.1 (Cary, USA). All thirty-six items of the nine health concepts were examined in relation to anthropometric measurements.

Standardising scores for the nine health concepts

Thirty-six items of reported health were appropriately converted and standardised into percentage scale based on the equation described by van der Zee and Sanderman (1995) and Medical Outcomes Trust (1994). These items were grouped accordingly to make up the nine health concepts (**Table 5.6.1**).

Definition of 'good' and 'poor' for the nine health concepts

Distributions of standardised scores were examined from the plots (not shown) to determine arbitrary cut-offs for the health concepts. It was decided that subjects with less than 66.7% of the standardised score were classified as having a 'poor' health concept, and those with 66.7% or above (i.e. upper tertile of the scores) were considered as having a 'good' health concept. For the health transition concept, which had only a two point scale, scores below 50% were considered as poor health, and 50% or above as good health. These cut-offs classified between 10 to 25% subjects as having 'poor' health for most concepts, except higher proportion subjects (40-50%) who had 'poor' vitality and 'poor' general health (**Appendix 5.6.2**).

Definition of 'good' and 'poor' health for the 36 individual items

Each item was arbitrarily dichotomised such that scores above average for items with an odd numbered scale (3 or 5 points) were considered as *'good' health* and average or lower as *'poor' health*. For items with *even scale* (2, 4 or 6 points), the scores for *'good' health* and *'poor' health* were evenly divided.

Logistic regression analysis

Odds ratios and 95% confidence intervals (CI) were determined to estimate the relative risks of 'poor' health in those with high BMI, WHR and large waist circumference, adjusted for age, lifestyle and demographic factors. Possible interactions between height and WHR, and height and waist circumference were examined using maximum likelihood analysis for the difference of chi square statistic when the interaction terms (combinations of tertiles) were added to the model, with reference to tallest subjects who had lowest (tertile 1) WHR, or lowest waist circumference. Similar analysis for the interaction between BMI and WHR was performed to see if fat distribution accentuated poor self-rated health in subjects of different fatness, with reference to those with lowest BMI and lowest WHR. Interactions between age and anthropometric measurements on health concepts were also examined, with reference to the youngest group (20-29 years) who had lowest BMI, lowest WHR, lowest waist circumference, or were tallest.

RESULTS

Subject characteristics are shown in **Table 5.6.1**. Tertiles of anthropometric variables in the present sample were identified at 87.3, 96.1 cm in men and 74.8, 84.0 cm in women for waist circumference; and 175.5, 181.5 cm in men and 163.0, 168.0 cm in women for height; 0.873, 0.938 in men and 0.756, 0.816 in women for WHR; 24.15, 26.84 kg/m^2 in men and 22.67, 25.63 kg/m^2 in women for BMI.

The present study examined a wide range of quality of life measures, found that they were related similarly to all indices of adiposity currently in use. For clarity of presentation, only results for items from the health concepts of physical functioning (10 items) and general health (5 items) in relation to waist circumference are tabulated in the present study.

Risks of 'poor' health indicated by the nine health concepts

After adjustment for age, and lifestyle and demographic factors, compared to those in tertile 1, those with waist circumference (**Figures 5.6.1a & b**), in tertile 3 were two to three times more likely to associate with 'poor' physical functioning (score <66.7%) and less strongly with other health concepts (results not shown). Similar results (data not presented) were observed for BMI and WHR.

Risks of 'poor' health indicated by the 36 individual items of health concepts

Results for items of physical functioning (10 items) and general health (5 items) are presented in **Tables 5.6.2** and **5.6.3**. Compared to those in the lowest tertile, the odds ratios, adjusted for age, lifestyle and demographic factors, for limitations in physical functioning were significantly higher in those with highest tertile of waist circumference (**Tables 5.6.2a** & **b**), and most marked in women in that they had more problems of lifting or carrying groceries, walking one flight of stairs or walking a distance of one block.

In men, those in the highest tertile of waist expected their health to get worse more often than those in the lowest tertile, and reported the answer for 'excellent' health as 'don't know' or as a 'false' statement. In women, those with largest waist circumference considered their health in general as 'not good'.

Of the remaining 16 items from the health concepts concerning social functioning, role limitations due to physical problems or emotional problems, mental health, vitality, pain, and health change since last year, only a few were related to anthropometry. For clarity, only significant odds ratios for high or low tertiles are reported in this section. Compared to subjects with lowest tertile, men with largest waist were 1.80 times (95% confidence interval 1.18 to 2.28) more likely to feel worn out a good bit to all the time (vitality item), women with largest waist were 1.33 times (1.00 to 1.72) more likely to feel they accomplished less than they would like with work or other regular daily activities in the past four weeks as a result of physical health problems (physical role functioning item), and 1.27 times (1.00 to 1.61) to not feel that they have a lot of energy a good bit to all the time (vitality item) with waist in the third tertile.

Analysis for interactions between anthropometric measures and age

Examination of interactions between anthropometric variables on the nine health concepts showed there were weak interactions (χ^2 range 8 to 10 with 4 degrees of freedom, P <0.05) in men and in women for only a few relationships. Logistic regression analysis was performed to identify the subgroup most related to poor health concepts. Compared to subjects with a combination of lowest BMI and lowest WHR, the odds ratio for role limitations due to physical problems was 9.5 (1.2 to 74.8) in men, and 'poor' general health was 1.98 (1.14 to 3.43) in women with highest BMI and highest WHR. Compared to those with both smallest waist and tallest height, the odds ratio for women who had 'poor' physical functioning was 2.01 (1.05 to 3.83) for those with largest waist and shortest height, and 2.95 (1.30 to 6.69) in women with both largest waist and tallest height. Adjusted odds ratio for women who had more bodily pain was 2.07 (1.20 to 3.57) in tallest women with largest waist. There was only one interaction between anthropometric measurements and age on health concepts, which was height in women ($\chi^2 = 22.8$, 6 degrees of freedom, $P < 0.01$). Compared to those 20-29 years and tallest, the odds ratio for 'poor' general health was 1.62 (1.01 to 2.61) in women aged 50-59 with height in tertile 2. There was no evidence for subjects with low BMI and high WHR having different health concepts from those with low BMI and low WHR.

DISCUSSION

In the present study quality of life measures related similarly to waist circumference, BMI and WHR. Compared to the lowest tertile, subjects with high BMI, high WHR or large waist circumference were more likely to have 'poor' physical functions, limiting many common, basic activities of daily living, including difficulties in walking several blocks and bending, kneeling or stooping. Women with adverse anthropometry had more severe problems than men such as walking one block, or one flight of stairs, lifting or carrying groceries. These results suggest that subjects who are overweight, with adverse fat distribution may be less able to care for themselves, their quality of life and possibly that of their relatives would be affected.

Examination of items from the general health concept showed that subjects with large waist were more likely to expect their health to get worse (men) and to consider their health in general as not good (women). The subjects' current indices of adiposity did not relate to reported change in health since one year previously, perhaps because some had changed weight and fat distribution as well as their health. Poor subjective health is a determinant of mortality independent of physical health status (Mossey and Shapiro, 1982; Kaplan and Camacho, 1983; Idler *et al*, 1990; Pijls *et al*, 1993). It has been shown that subjects who performed activities of daily living with difficulties were at 2 to 3 times more at risk of death (Kaplan *et al*, 1988).

Unadjusted odds ratios were higher (results not shown), age had the most powerful confounding effects on the relationships between anthropometric variables and quality of life. We found no important interactions between height and waist circumference or WHR, or interactions between age and BMI, WHR or waist circumference.

The present study defined 'good' health based on the 9 health concepts as equal or above 66.7% and 'poor' health as below 66.7% (except for health transition health concept which used 50%) standardised scores respectively. There are no definitive cut-offs for these health concepts, but Stewart *et al* (1994) have shown that patients with chronic diseases who were more physically active had scores mostly above 66.7% and those who were less active had scores mostly below 66.7%. 'Good' health indicated by the 36 individual items was defined as above average scores and poor health items as average or below scores. These cut-offs were arbitrary, if good self rated health was defined more broadly, i.e. average or above scores, then the prevalence of poor self rated health would be lower. Launer *et al* (1994) also categorised fair and poor scores together, based on their strong association with disability. Previous findings have shown that elderly subjects above 65 years who rated their health as fair had twice the risk of death within two years compared to those who rated their health as excellent (Mossey and Shapiro, 1982), and Schoenfeld *et al* (1994) found the risk of death in those whose self rated health was fair was similar to subjects with poor rating. There may be an overrating of health amongst those who consider their health as fair (Maddox and Douglass, 1973; LaRue *et al*, 1979). Poorly rated health was associated with adverse adiposity, but questions were not designed to assess self rated health addressing the subjects own perception of this link.

Quality of life may include many dimensions, psychosocial health is probably one example, and its association with overweight and fat distribution has been extensively studied. Negative attitudes towards overweight (Staffieri, 1978), peer pressure, and social discrimination impose heavy pressure upon these persons (Allon, 1979; Sobal *et al*, 1995). Severely overweight men (BMI >34 kg/m^2) and women (BMI >38 kg/m^2) have been shown to rate their current health as poorer and mood states less positive than non-overweight subjects (Sullivan *et al*, 1993). Even at an early age (9 years), overweight children have been shown to have low self-esteem (Hill and Silver, 1995). The fear of being overweight may lead to behavioural changes such as slimming, particularly in women who are not even overweight (Seidell *et al*, 1986a). Despite their apparent associations with unfavourable perceptions by others, and with poor physical health, there was little evidence in the present study to suggest that overweight subjects, those with central fat distribution, or large waist were having more non-physical problems such as mental health, social functioning, or role limitations due to emotional problems.

CONCLUSION

This study provides convincing evidence that large waist circumference, high WHR and high BMI are important indicators of physical difficulties with simple daily activities. The data present a very worrying profile of ill health and disabilities, affecting a large and increasing proportion of adults.

Table 5.6.1. Characteristics, and raw and standardised self rated health scores of 1885 men and 2156 women. Low scores indicate poor health, and high scores indicate good health.

	Men			Women		
Characteristics	Mean	SD	Range	Mean	SD	Range
Age (years)	42.7	10.9	20.3-60.0	41.4	11.0	20.2-59.9
Weight (kg)	82.2	12.3	45.7-157.0	68.4	11.5	38.6-153.0
Height (m)	1.79	0.07	1.52-2.06	1.66	0.07	1.42-1.89
Body mass index (kg/m^2)	25.7	3.6	15.7-50.1	24.8	4.1	16.5-58.3
Waist circumference (cm)	92.2	11.0	64.0-155.0	80.9	11.1	60.0-135.5
Hip circumference (cm)	101.6	6.8	69.0-150.0	101.8	8.3	74.4-160.0
Waist to hip ratio	0.907	0.073	0.621-1.369	0.793	0.072	0.603-1.302
Raw score						
Physical functioning	28.1	3.2	10.0-30.0	27.5	3.4	10.0-30.0
Social functioning	9.0	1.6	2.0-10.0	8.7	1.8	2.0-10.0
Role limit-physical‡	7.4	1.2	4.0-8.0	7.2	1.4	4.0-8.0
Role limit-emotional§	5.5	0.9	3.0-6.0	5.4	1.0	3.0-6.0
Mental health	24.0	3.9	6.0-30.0	23.0	4.1	5.0-30.0
Vitality	17.6	3.5	4.0-24.0	16.7	3.6	4.0-24.0
Bodily pain	51.9	10.2	11.0-60.0	50.0	10.7	11.0-60.0
General health	19.2	3.5	5.0-25.0	19.1	3.5	5.0-25.0
Health transition	3.0	0.6	1.0-5.0	3.1	0.7	1.0-5.0
*Standardised score**						
Physical functioning	90.3	15.8	0.0-100.0	87.6	16.8	0.0-100.0
Social functioning	86.9	20.4	0.0-100.0	83.5	22.1	0.0-100.0
Role limit-physical†	84.7	29.5	0.0-100.0	79.7	34.0	0.0-100.0
Role limit-emotional‡	85.0	30.3	0.0-100.0	80.4	34.9	0.0-100.0
Mental health	76.2	15.6	4.0-100.0	72.2	16.4	0.0-100.0
Vitality	67.9	17.4	0.0-100.0	63.5	17.9	0.0-100.0
Bodily pain	83.5	20.9	0.0-100.0	79.7	21.9	0.0-100.0
General health	70.8	17.4	0.0-100.0	70.4	17.7	0.0-100.0
Health transition	49.6	15.5	0.0-100.0	52.2	17.3	0.0-100.0

*Calculated using equation from van der Zee and Sanderman (1995); †role limitations due to physical functioning problems; ‡role limitations due to emotional problems.

Table 5.6.2. Age and lifestyle adjusted odds ratios of poor scores (<67.7% of standardised scores) for individual items describing physical functioning in second and third tertiles (first tertile as reference) of waist circumference.

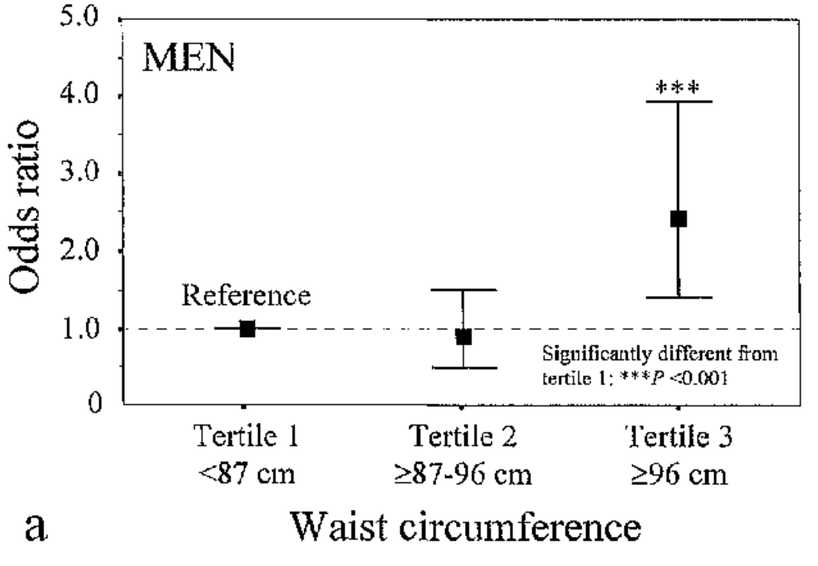
	Tertile 1	Tertile 2		Tertile 3	
Items of physical functioning	Odds ratio	Odds ratio	95% CI	Odds ratio	95% CI
MEN (n = 1885)					
Vigorous activities	1.00	1.21	0.95, 1.55	1.68***	1.29, 2.17
Moderate activities	1.00	1.04	0.70, 1.54	1.58*	1.08, 2.33
Lifting or carrying groceries	1.00	1.03	0.73, 1.45	1.34	0.95, 1.90
Walking several flights of stairs	1.00	0.99	0.67, 1.45	2.16***	1.50, 3.11
Walking one flight of stairs	1.00	0.66	0.37, 1.17	1.27	0.75, 2.13
Bending or kneeling	1.00	1.11	0.82, 1.50	1.75***	1.30, 2.36
Walking more than a mile	1.00	1.28	0.88, 1.87	2.31***	1.60, 3.34
Walking several blocks	1.00	1.04	0.61, 1.77	2.23**	1.36, 3.65
Walking one block	1.00	0.95	0.52, 1.74	1.71	0.97, 3.01
Bathing or dressing	1.00	1.25	0.62, 2.52	1.83	0.93, 3.60
WOMEN (n = 2156)					
Vigorous activities	1.00	1.20	0.96, 1.49	1.68***	1.32, 2.13
Moderate activities	1.00	1.27	0.95, 1.69	1.78***	1.34, 2.36
Lifting or carrying groceries	1.00	1.11	0.86, 1.43	1.45**	1.12, 1.87
Walking several flights of stairs	1.00	1.19	0.89, 1.60	1.87***	1.40, 2.49
Walking one flight of stairs	1.00	1.11	0.70, 1.76	1.88**	1.22, 2.90
Bending or kneeling	1.00	1.24	0.95, 1.63	2.20***	1.68, 2.87
Walking more than a mile	1.00	1.15	0.85, 1.57	1.75***	1.29, 2.38
Walking several blocks	1.00	1.00	0.65, 1.54	1.73**	1.15, 2.58
Walking one block	1.00	1.01	0.62, 1.66	1.22	0.75, 1.97
Bathing or dressing	1.00	1.04	0.55, 1.99	0.80	0.40, 1.59

***P <0.001, **P <0.01, *P <0.05; CI = confidence interval.

Table 5.6.3. Age and lifestyle adjusted odds ratios of poor scores (<67.7% of standardised scores) for individual items describing general health in second and third tertile (first tertile as reference) waist circumference.

	Tertile 1	Tertile 2		Tertile 3	
Items of general health	Odds ratio	Odds ratio	95% CI	Odds ratio	95% CI
MEN (n = 1885)					
Poor health in general	1.00	1.04	0.71, 1.53	1.23	0.83, 1.81
Getting sick a little easier	1.00	1.17	0.84, 1.64	1.23	0.86, 1.75
Health not as good as anybody	1.00	1.14	0.89, 1.45	0.97	0.75, 1.27
Expecting worse health	1.00	1.28*	1.01, 1.62	1.39*	1.08, 180
No excellent health§	1.00	1.30	0.98, 1.73	1.35*	1.00, 1.82
WOMEN (n = 2156)					
Poor health in general	1.00	0.91	0.64, 1.27	1.52*	1.09, 2.13
Getting sick a little easier	1.00	0.85	0.64, 1.12	1.18	0.89, 1.57
Health not as good as anybody	1.00	1.11	0.88, 1.40	0.97	0.76, 1.24
Expecting worse health	1.00	1.03	0.82, 1.28	0.96	0.75, 1.21
No excellent health§	1.00	1.09	0.84, 1.41	1.28	0.99, 1.67

***P <0.001, **P <0.01, *P <0.05; CI = confidence interval; §responded as "don't know" or "false" to the question " do you rate your health as excellent? (dont't know, true or false)".



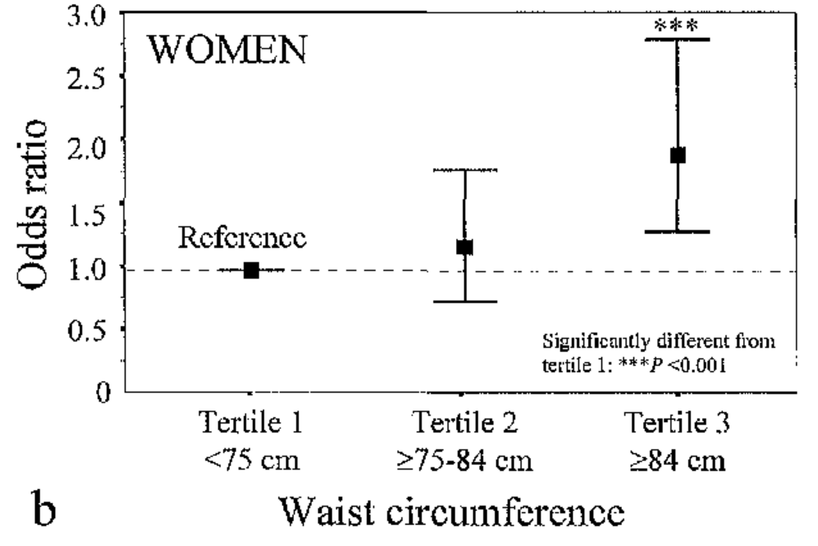


Figure 1. Odds ratios (95% confidence intervals) for subjects with 'poor' (<66.7% of standardised scores) physical functioning health concept in different tertiles of waist circumference in men (a) and in women (b) (Odds ratios were adjusted for age, cigarette smoking, alcohol drinking, physical activity, educational level, marital status, employment, household composition, intimate contact, and parity (in women).

Appendix 5.6.1. Age, lifestyle and demographic factors as possible confounders considered in analysis of the associations of quality of life with body mass and fat distribution.

	Reference group	Dummy variables		
		1	2	3
Age (years)	20-29	30-39	40-49	50-59
Smoking	Non-smokers	Ex-smokers	Current smokers	
Alcohol consumption (glasses/day)	Occasional (<1)	None (0)	Moderate (1 to <3)	Heavy (≥3)
Physical activity	Active (do sport)	Inactive (do no sport)		
Educational level	Level 3 (higher vocational or university)	Level 2 (vocational or higher secondary)	Level 1 (lower than secondary)	
Marital status	Single	Married or cohabiting	Divorced or widowed	
Employment	Currently employed	Unemployed	Housewives	Retired*
Household composition	Living with someone	Living with no one		
Intimate contact†	No one	1-2	3-5	≥6
Parity (live births)	None	1-2	≥3	

*Retired early; †Discussing personal matters with other people.

Appendix 5.6.2. Proportions of subjects with standardised scores below 66.67% for the nine health concepts in the RAND-36 questionnaire.

	Men (%)	Women (%)
Physical functioning	8.44	10.76
Social functioning	17.24	23.47
Role limit-physical‡	16.82	23.01
Role limit-emotional§	23.45	27.92
Mental health	21.49	30.10
Vitality	43.98	54.27
Bodily pain	15.44	21.10
General health	37.61	38.78
Health transition	13.32	12.52

CHAPTER SIX

EPIDEMIOLOGICAL MORPHOLOGY AND ASSOCIATED ILL HEALTH BASED ON STANDARD CUT-OFFS VALUES OF ANTHROPOMETRIC MEASURES

CONTENTS OF CHAPTER SIX **PAGES**

— 6.1 —

IMPAIRMENT OF HEALTH AND QUALITY OF LIFE IN THE OVERWEIGHT ACCORDING TO STANDARD CUT-OFFS OF BODY MASS INDEX

This section has been submitted for publication as

Lean MEJ, **Han TS**, Seidell JC. Impairment of health and quality of life in the overweight according to standard cut-offs of body mass index. (submitted).

Collaboration with MORGEN project

ABSTRACT

Objective: To estimate the prevalence and risks of chronic disease, secondary symptoms and poor quality of life associated with overweight, using standardised body mass index (BMI) cut-offs (25 and 30 kg/m^2).

Design: Cross-sectional study in a random sample set in the Netherlands.

Subjects: 5887 men and 7018 women aged 20-59 years selected from the civil registry of Amsterdam, Maastricht and Doetinchem.

Main outcome measures: Symptoms of respiratory insufficiency, low back pain, type 2 diabetes, cardiovascular risk factors, and physical functioning.

Results: People with BMI below 25 kg/m^2 were considered the reference group, with low prevalence of symptoms of obesity-related diseases and good subjective health. Between 25-30 kg/m^2, the prevalences of these all increased, and above 30 kg/m^2 were greatly increased. After adjustments for age and lifestyle factors, odds ratios (95% confidence intervals) in those with a BMI ≥30 kg/m^2 were 3.5 (2.8 to 4.4) in men and 3.3 (2.8 to 3.9) in women for shortness of breath when walking upstairs, 4.6 (2.4 to 8.8) in men and 5.4 (2.8 to 10.5) in women for type 2 diabetes, 5.5 (4.5 to 6.6) in men and 2.9 (2.4 to 3.4) in women for at least one major cardiovascular risk factor. Both men and women with BMI ≥30 kg/m^2 were twice as likely to have difficulties in performing a range of basic daily physical activities. Compared to women with BMI <25 kg/m^2, those with BMI ≥30 kg/m^2 were 1.5 times more likely to have symptoms of intervertebral disc herniation. Significantly more overweight women had problems associated with low back pain including hindrance to their daily business, absence from work and medical consultation. The calculated population attributable risks to estimate the excess risk of ill health attributable to overweight were between 10-40%.

Conclusions: Health risks for a range of problems are presented using the standard BMI cut-offs. Overweight is associated with increased risks of chronic disease, secondary symptoms and impairment of quality of life, which could amount to huge health care expenditure.

INTRODUCTION

Health service burdens are heavily imposed by clusters of symptoms, risk factors and secondary diseases associated with overweight and adverse fat distribution, leading to coronary heart disease, strokes, non-insulin dependent diabetes mellitus (NIDDM), and several cancers. Recent estimates costs per annum for treating this ill health were 195 million pounds in Britain (Office of Health Economics, 1994), and 70 billion dollars in the United States (Institute of Medicine, 1995). These figures present major concerns to the health service, since the prevalence of overweight is still rising in many countries (Kuczmarski, 1992; Seidell 1995a; Bennett *et al*, 1995; Gregory *et al*, 1990).

Estimating total burdens of disease and financial costs associated with overweight has been hampered by a lack of consistent evidence using standard cut-offs for body mass index (BMI) and standardised referent populations. From the ongoing MORGEN project (monitoring cardiovascular health in The Netherlands), we have shown that waist circumference, BMI and waist to hip ratio all relate closely and similarly to a variety of symptoms and chronic diseases (**Chapter 5**). Hitherto, data have been analysed by tertiles of BMI, and division by median, tertiles, and quintiles have been performed for epidemiological research for statistical reasons.

The present study summarises the prevalence of major chronic diseases, symptoms and impairment of quality of life related to overweight, and calculated the odds ratios according to the BMI categories adopted by World Health Organisation (1995) - i.e. BMI $\geq$25 kg/m^2, or BMI $\geq$30 kg/m^2, with reference to BMI <25 kg/m^2.

METHODS

Subjects

Dutch men (n = 5887) and women (n = 7018) aged 20-59 were recruited randomly from civil registries for the ongoing MORGEN (Monitoring Risk Factors and Health in The Netherlands) project 1993 to 1995 cohorts, from Amsterdam, Maastricht, and Doetinchem. To obtain similar numbers of subjects at each age, the sample was stratified by sex and five year age group. The response rate to invitations was about 50%. Information on quality of life was available in the 1995 cohort of 1885 men and 2156 women. The numbers of subjects in the present study represent those who attended health centres for biochemical and physiological measurements.

Measurements

All anthropometric measurements were made according to the World Health Organisation (1995) recommendations by trained paramedical personnel. Subjects wore light clothes during measurements of body weight to the nearest 100g using calibrated scales, height in bare feet to the nearest mm. BMI was calculated as weight (kg) divided by height squared (m^2). Lifestyle factors were obtained from a questionnaire.

Symptoms and diseases

Major symptoms and diseases associated with overweight were selected from our previous studies (**Chapter 5**). Symptoms of respiratory insufficiency included shortness of breath, wheezing, coughing and bringing up phlegm (**Chapter 5.4**). Risk factors for cardiovascular disease included hypercholesterolaemia (plasma total cholesterol $\geq$6.5 mmol/l), low high density lipoprotein cholesterol ($\leq$0.9 mmol/l) and hypertension (systolic blood pressure $\geq$160 mmHg and/or diastolic blood pressure $\geq$95 mmHg and/or the use of antihypertensive agents) (**Chapter 5.2**; Han *et al*, 1995c). Known and newly diagnosed (random blood glucose $\geq$11.1 mmol/l) NIDDM were included, and insulin treated patients were excluded as indistinguishable from insulin dependent diabetes mellitus (**Chapter 5.5**; Seidell *et al*, 1997). Symptoms of low back pain were obtained from questionnaire. Those who responded affirmatively to having *low back pain in the past 12 months*, were then asked whether they had radiating pain to the knees or feet, to indicate *symptoms of intervertebral disc herniation.* This symptom was only accepted in the presence of low back pain, to avoid including those with other causes of radiated pain. The subjects were asked about the total duration of low back pain in the past 12 months. Those who had low back pain for a total of twelve weeks or more were classified as having *chronic low back pain*. The *reference groups* for the three classes of low back pain were composed of those who did not fulfil the criteria for the symptom under analysis, thus the reference group when analysing one symptom included some subjects with other symptom(s) of low back pain (**Chapter 5.3**; Han *et al*, 1997d). From *ten items* rated by subjects using the standardised Dutch RAND-36 questionnaire, which has been adapted from the standardised SF-36 Health Survey the concept of physical functioning, was calculated to represent quality of life. Distributions of standardised scores were examined from the plots (not shown) to determine arbitrary cut-offs for the health concepts. It was decided arbitrarily that subjects with *less than 66.7% of the standardised score* would be classified as having a *'poor' health concept*, and those with *66.7% or above* were considered as having a *'good' health concept*. This cut-off classified 8.4% of all men and 10.8% of all women as having 'poor' physical functioning. Each of the ten items comprising the physical functioning health concept was arbitrarily dichotomised such that scores above average (with an odd numbered scale of 3 or 5 points) were considered as *'good' health*, and average or lower scores were classed as *'poor' health*. For items with *even scale* (2, 4 or 6 points), the scores for *'good' health* and *'poor' health* were evenly divided (**Chapter 5.6**).

Lifestyle and demographic factors as confounding factors

Dummy variables (**Appendix 6.1.1**) for possible confounding factors were created to adjust for the associations between adiposity and health concepts and individual items.

Statistical methods

Statistical analyses were performed using SAS version 6.1 (Cary, USA). Logistic regression analysis was used to estimate the odds ratios and 95% confidence intervals of symptoms of disease and 'poor' quality of life in those with BMI in the categories of between 25-30 kg/m^2 and ≥30 kg/m^2, compared to those with body mass index <25 kg/m^2, adjusted for age, lifestyle and demographic factors (**Appendix 6.1.1**).

Population attributable risk

The population attributable risk, i.e. the proportionate excess risk of ill health associated with exposure to the risk of overweight based on BMI cut-off at 25 kg/m^2 (PAR_{25}) was calculated as (Kahn and Sempos, 1989; Kleinbaum *et al*, 1982):

$$PAR_{25} = P_{25} \times (OR_{25} - 1)/[P_{25} \times (OR_{25} - 1)] + 1,$$

where P_{25} is the proportion of subjects exposed to the risk of overweight, i.e. all subjects with BMI ≥25 kg/m^2, OR_{25} is the age and lifestyle adjusted odds ratio for a symptom or disease in subject group with BMI ≥25 kg/m^2 compared to the reference group with BMI <25 kg/m^2. Population attributable risk using BMI cut off at 30 kg/m^2 (PAR_{30}) was calculated the same way, with the proportion of subjects exposed to BMI ≥30 kg/m^2, and the odds ratios for a disease in subjects with BMI ≥30 kg/m^2 compared to the reference group with BMI <30 kg/m^2. The difference between PAR_{25} and PAR_{30} gives $PAR_{25\text{-}30}$ for BMI between 25-30 kg/m^2. This equation is valid only when the odds ratio is equal or greater than 1.

RESULTS

Characteristics of subjects are shown in **Table 6.1.1**. Overall prevalence of disease, symptoms and poor quality of life is shown in **Table 6.1.2**. There were 45% men and 31% women whose BMI were between 25-30 kg/m^2 and 11% men and 11% women above 30 kg/m^2. The prevalence of these health risks increased with increasing BMI (**Tables 6.1.3a & b**), and highest in those with BMI above 30 kg/m^2. **Figures 6.1.1a & b** show that within separate groups of non-smokers and smokers, the prevalence of those with shortness of breath when walking uphill or upstairs increased with increasing BMI, and significantly (P <0.001) higher in smokers for each level of BMI.

After adjustments for age and appropriate lifestyle factors, compared to those with BMI below 25 kg/m^2, the risk for chronic disease, symptoms and quality of life increased significantly (**Tables 6.1.4a & b**), with the highest risk in those with BMI above 30 kg/m^2. **Figure 6.1.2** shows the proportions of subjects whose daily life activities were affected by low back pain. About a third of men and women reported that, due to low back pain, their daily business was hindered, they had to be absent from work, and more than forty percent sought medical consultation as a result of low back pain. **Table 6.1.5** shows that after adjustments for age and lifestyle factors, the proportions of these consequences of low back pain were significantly higher in women with BMI above 30 kg/m^2 compared to women with BMI below 25 kg/m^2. The proportion of daily business hindered due to low back pain was significantly higher in men with BMI 30 kg/m^2 compared to men with BMI below 25 kg/m^2. **Figure 6.1.3** shows the odds ratios (95% confidence interval limits) for 'poor' physical function health concept were two and half times higher in subjects with BMI above 30 kg/m^2 compared to those with BMI below 25 kg/m^2.

Tables 6.1.6 a & b show the proportions of subjects 'exposed' to overweight, with BMI above 25, or 30 kg/m^2, and the odds ratios for ill health. These values were used to calculate the population attributable risks for symptoms of disease and 'poor' quality of life in those with BMI ≥25 or ≥30 kg/m^2. **Table 6.2.7** shows that the excess proportions of subjects with poor health attributable to overweight (BMI ≥25 kg/m^2) were approximately 10 to 40 percent. The difference in population attributable risks from BMI categories of ≥25 and ≥30 kg/m^2 is the population attributable risk for those with a BMI between 25 to 30 kg/m^2. This difference of population attributable risk was as high as the values for category above 30 kg/m^2.

DISCUSSION

Attempts to quantify the impact of obesity on health and health service costs have been confused by lack of standardisation. For example, the relative risks for NIDDM have been quoted as up to 40 for men with BMI above 30 kg/m^2 or 93 for women with BMI above 35 kg/m^2, depending on the reference population used (Chan *et al*, 1994; Colditz *et al*, 1995). Some use all those below the cut-off, others obtain very high relative risks by using the lowest risk group, e.g. BMI <22 kg/m^2 as the reference population. Many epidemiological studies have compared risks in tertiles of populations often with BMI tertile range (25-27 kg/m^2). Surprisingly few studies have estimated health risks in groups which would be considered obese, i.e. BMI ≥ 30 kg/m^2 (WHO, 1995). The present study has combined data from a number of analyses which have shown that overweight, indicated by BMI in the highest tertile is associated with increased risk of chronic disease, symptoms and risk factors of major diseases, and poor quality of life in terms of difficulties in performing basic activities of daily living (**Chapter 5**). The data are presented here in a standardised format, relating prevalences of a range of health problems in the overweight to those in a referent population with BMI <25 kg/m^2. Using this approach it is now possible to derive population attributable risks (**Table 6.1.6**) in a consistent way for estimating the cost obesity in different countries. The BMI cut-offs employed (BMI 25-30, ≥ 30 kg/m^2) are conventional for most of the world, and have been adopted by WHO (1995). Even in this relatively large, detailed study, numbers preclude divisions into smaller categories, e.g. by BMI 28 kg/m^2, or BMI ≥ 35 kg/m^2.

The Dutch population studied has physical characteristics similar to those of most Western/Caucasian populations, so the data can probably be generalised with caution. The patterns of health problems associated with being overweight are similar to those identified by analysis of tertiles, so most are significantly affected by BMI class. For some symptoms the increased prevalence with BMI ≥ 30 kg/m^2 is particularly striking, e.g. shortness of breath when walking upstairs or uphill is present in 46% of women and 34% of men, chronic low back pain in 25% women, 20% men. It is also clear that the BMI range 25-30 kg/m^2 is not benign, with respect to elevated cardiovascular risk factors in both sexes, and a wide range of important symptoms in women (**Table 6.1.4**). The increased prevalence of shortness of breath is again striking at almost 30% of women with BMI 25-30 kg/m^2 and we have previously shown that overweight affects shortness of breath in both smokers and non-smokers (**Chapter 5.4**).

In addition to these analyses, which should be of value to health economics and policy makers. **Table 6.1.5** presents new data on some major social consequences of being overweight. Again it is clear that BMI 25-30 kg/m^2 after appropriate adjustments for age, smoking and education, has a significant impact amongst women, although these problems only become apparent with ≥30 kg/m^2 in men. Odds ratios are likely to be overestimated if the prevalence is high (Lee, 1994). Thus the results of some items of the physical functioning health concept (**Tables 6.1.3a & b**) in the present study should be interpreted with caution.

It is a potential limitation of the present analysis that the age range of subjects was 20-59 years. Some of the conditions and symptoms under study (e.g. NIDDM, shortness of breath) are well known to be much more prevalent in the elderly - indeed the majority of NIDDM patients are aged over 60 years. On the other hand, the impact of overweight or obesity, measured as odds ratio may not be age related, and the present study did not find any such relationship. In the present study there were too few NIDDM subjects for subgroup analysis, but compared to the reference group (BMI <25 kg/m^2), the odds ratios for respiratory symptoms and cardiovascular risk factors in the overweight (BMI 25-30 kg/m^2 or ≥30 kg/m^2) remained similar in different age bands. In the absence of directly comparable data in elderly subjects it therefore seems reasonable to apply standard figures of odds ratios for men and women, of all ages. **Table 6.1.7** shows the population attributable risks based on BMI 25 and 30 kg/m^2, providing standard values for estimating excess costs of ill health due to overweight.

CONCLUSIONS

The results of this study provide justification for using BMI 25 and 30 kg/m^2 as cut-offs to indicate medical concern for a range of complications. The data for the first time allow prediction of the burden of disease to be made in a consistent way using standard WHO (1995) cut-offs of BMI.

Table 6.1.1. Characteristics of 5887 men and 7018 women.

	Men			Women		
	Mean	SD	Range	Mean	SD	Range
Age (years)	42.9	10.7	20.3-60.0	42.2	11.0	20.2-59.9
Weight (kg)	82.0	12.0	44.4-157.0	68.5	11.5	36.6-153.0
Height (cm)	178.4	7.3	152.0-210.0	165.7	6.7	134.5-190.0
Body mass index (kg/m^2)	25.8	3.5	15.7-50.1	25.0	4.2	14.9-58.3
Waist circumference (cm)	92.3	10.8	64.0-155.0	81.0	11.1	56.5-150.0
Hip circumference (cm)	101.8	6.6	69.0-150.0	102.2	8.4	76.4-165.0
Waist to hip ratio	0.905	0.072	0.621-1.369	0.791	0.070	0.567-1.302

Table 6.1.2. Unadjusted prevalence in total population of 5887 men and 7018 women (1885 men and 2156 women had information on quality of life) with chronic disease, symptoms and poor quality of life.

	Men		Women	
	%	95% CI	%	95% CI
Respiratory symptoms				
Wheezing when not having a cold	9.2	8.5, 10.0	8.4	7.7, 9.2
Woken up by shortness of breath	5.0	4.4, 5.6	6.1	5.5, 6.7
Coughing for more than 3 months	7.7	7.0, 8.4	7.5	6.8, 8.2
Bring up phlegm for more than 3 months	6.8	6.2, 7.5	5.0	4.3, 5.6
Shortness of breath when walking uphill/stairs	16.0	15.1, 17.0	24.7	23.7, 25.6
Shortness of breath when walking with others	4.6	4.0, 5.1	7.4	6.9, 7.9
Cardiovascular risk factors				
High total cholesterol (≥6.5 mmol/l)	14.6	13.7, 15.5	13.5	12.7, 14.3
Low HDL-cholesterol (≤0.9 mmol/l)	21.3	20.3, 22.3	5.1	4.6, 5.6
Hypertension*	10.3	9.5, 11.1	8.3	7.7, 8.9
At least one risk factor	38.0	36.8, 39.3	23.5	22.5, 24.5
Diabetes				
Non-insulin dependent diabetes mellitus	1.6	1.3, 1.9	0.9	0.7, 1.2
Symptoms of low back pain				
Chronic low back pain (total ≥12 weeks/year)	16.6	15.6, 17.6	20.5	19.6, 21.4
Symptoms of intervertebral disc herniation	13.4	12.5, 14.3	17.6	16.7, 18.4
'Poor' quality of life				
Difficulties in physical functioning				
Vigorous activities†	50.1	47.8, 52.4	54.0	51.7, 56.3
Moderate activities†	13.7	12.1, 15.3	24.1	22.5, 25.7
Lifting/carrying groceries†	17.5	15.8, 19.3	32.6	30.8, 34.3
Walking several flights of stairs†	15.8	14.1, 17.4	22.2	20.5, 23.9
Walking one flight of stairs†	6.4	5.2, 7.5	8.9	7.8, 10.0
Bending, kneeling†	25.4	23.4, 27.4	28.2	26.2, 30.2
Walking more than a mile†	15.2	13.5, 16.8	18.4	16.7, 20.0
Walking several blocks†	8.0	6.8, 9.3	9.4	8.2, 10.7
Walking one block†	5.5	4.4, 6.5	6.5	5.4, 7.5
Bathing or dressing†	4.0	3.1, 4.9	3.1	2.2, 4.0
'Poor' physical functioning concept‡	8.4	7.2, 9.7	10.8	9.5, 12.0

*Systolic ≥160 or diastolic blood pressure ≥95 mmHg or medication for hypertension; †single items of physical functioning concept; ‡<66.7% standardised scores.

Table 6.1.3a. Unadjusted prevalence of subjects with chronic disease, symptoms and poor quality of life in different categories of body mass index, in men.

Men	Body mass index (kg/m^2)			χ^2
	<25	25-30	≥30	
Proportions of subjects	*(44.0)*	*(45.2)*	*(10.8)*	
Respiratory symptoms				
Wheezing when not having a cold	8.5	9.3	12.1	7.9*
Woken up by shortness of breath	4.6	5.1	6.5	4.0
Coughing for more than 3 months	7.9	7.6	7.4	0.2
Bring up phlegm for more than 3 months	6.6	6.8	7.7	0.9
Shortness of breath when walking uphill/stairs	11.2	16.4	34.3	203.3***
Shortness of breath when walking with others	3.1	4.3	113	79.7***
Cardiovascular risk factors				
High total cholesterol (≥6.5 mmol/l)	9.4	17.2	24.6	122.0***
Low HDL-cholesterol (≤0.9 mmol/l)	13.5	24.5	39.7	239.0***
Hypertension†	3.7	13.1	25.7	308.4***
At least one risk factor	23.6	45.1	66.9	510.2***
Diabetes				
Non-insulin dependent diabetes mellitus	0.6	1.8	4.7	57.9***
Low back pain				
Chronic low back pain (total ≥12 weeks/year)	14.5	17.9	20.0	17.1***
Symptom of intervertebral disc hermiation	10.9	15.0	16.4	24.6***
'Poor' quality of life				
Difficulties in physical functioning				
Vigorous activities‡	43.9	52.1	66.4	36.0***
Moderate activities‡	10.8	14.8	20.4	14.7***
Lift/carry groceries‡	14.2	18.4	26.5	18.6***
Walking several flights of stairs‡	10.8	16.9	30.8	52.0***
Walking one flight of stairs‡	5.3	6.1	11.9	12.4***
Bending, kneeling‡	20.9	24.7	45.5	53.8***
Walking more than a mile‡	11.5	15.9	26.1	28.4***
Walking several blocks‡	5.8	8.7	14.2	17.2***
Walking one block‡	4.7	5.0	10.4	11.4***
Bathing or dressing‡	2.9	4.1	8.1	11.4***
'Poor' physical functioning concept§	5.3	9.1	18.0	36.2***

***P <0.001, **P <0.01, *P <0.05; †systolic ≥160 or diastolic blood pressure ≥95 mmHg or medication for hypertension; ‡single items of physical functioning concept; §<66.7% standardised scores.

Table 6.1.3b. Unadjusted prevalence of subjects with symptoms of disease and poor quality of life in categories of body mass index, in women.

Women	Body mass index (kg/m^2)			χ^2
	<25	25-30	≥30	
Proportions of subjects	*(58.1)*	*(30.6)*	*(11.4)*	
Respiratory symptoms				
Wheezing when not having a cold	7.1	9.2	13.3	35.8***
Woken up by shortness of breath	5.1	7.4	8.2	19.6***
Coughing for more than 3 months	6.2	8.9	10.7	27.6***
Bring up phlegm for more than 3 months	4.2	5.4	7.6	17.7***
Shortness of breath when walking uphill/stairs	18.4	28.5	46.4	304.8***
Shortness of breath when walking with others	4.5	9.5	19.6	226.9***
Cardiovascular risk factors				
High total cholesterol (≥6.5 mmol/l)	9.4	19.1	19.8	143.4***
Low HDL-cholesterol (≤0.9 mmol/l)	3.4	5.8	11.8	101.8***
Hypertension†	3.9	10.6	24.6	395.8***
At least one risk factor	15.4	30.8	45.4	424.2***
Diabetes				
Non-insulin dependent diabetes mellitus	0.4	1.0	3.8	82.4***
Low back pain				
Chronic low back pain (total ≥12 weeks/year)	17.8	24.2	24.7	44.9***
Symptom of intervertebral disc hermiation	14.9	20.0	25.1	59.9***
'Poor' quality of life				
Difficulties in physical functioning				
Vigorous activities‡	47.9	60.3	72.4	60.6***
Moderate activities‡	18.4	31.7	36.0	60.7***
Lift/carry groceries‡	25.7	40.9	49.1	76.1***
Walking several flights of stairs‡	16.2	28.4	39.5	80.6***
Walking one flight of stairs‡	5.4	11.6	21.5	69.7***
Bending, kneeling‡	20.7	36.7	48.3	103.3***
Walking more than a mile‡	14.4	21.8	31.6	45.4***
Walking several blocks‡	6.7	11.3	20.2	45.2***
Walking one block‡	4.5	7.3	15.4	38.8***
Bathing or dressing‡	2.8	2.9	5.7	5.7
'Poor' physical functioning concept§	7.1	14.1	22.8	59.6***

***P <0.001, **P <0.01, *P <0.05; †systolic ≥160 or diastolic blood pressure ≥95 mmHg or medication for hypertension; ‡single items of physical functioning concept; §<66.7% standardised scores.

Table 6.1.4a. Odds ratios for chronic disease, symptoms and poor quality of life in categories of body mass index, adjusted for age and lifestyle factors (see **Appendix 6.1.1**), in men.

Men	Body mass index (kg/m^2)			
	25-30		≥30	
	OR†	95% CI	OR†	95% CI
Respiratory symptoms				
Wheezing when not having a cold	1.14	0.94, 1.40	1.50**	1.13, 2.01
Woken up by shortness of breath	1.04	0.80, 1.35	1.22	0.84, 1.79
Coughing for more than 3 months	0.98	0.79, 1.21	0.88	0.62, 1.25
Bring up phlegm for more than 3 months	1.00	0.79, 1.25	1.06	0.75, 1.50
Shortness of breath when walking uphill/stairs	1.43***	1.20, 1.69	3.51***	2.82, 4.38
Shortness of breath when walking with others	1.18	0.87, 1.59	2.85***	2.01, 4.04
Cardiovascular risk factors				
High total cholesterol (≥6.5 mmol/l)	1.58***	1.33, 1.88	2.22***	1.76, 2.81
Low HDL-cholesterol (≤0.9 mmol/l)	2.26***	1.94, 2.63	4.78***	3.87, 5.90
Hypertension‡	2.89***	2.27, 3.68	5.88***	4.43, 7.79
At least one risk factor	2.37***	2.09, 2.69	5.45***	4.48, 6.63
Diabetes				
Non-insulin dependent diabetes mellitus	1.98*	1.10, 3.60	4.59***	2.41, 8.78
Low back pain				
Chronic low back pain (total ≥12 weeks/year)	1.02	0.88, 1.20	1.05	0.83, 1.32
Symptom of intervertebral disc hermiation	1.31	0.95, 1.34	1.12	0.87, 1.44
'Poor' quality of life				
Difficulties in physical functioning				
Vigorous activities§	1.13	0.92, 1.40	1.78***	1.27, 2.51
Moderate activities§	1.15	0.83, 1.58	1.38	0.89, 2.14
Lift/carry groceries§	1.06	0.80, 1.42	1.42	0.96, 2.11
Walking several flights of stairs§	1.44*	1.05, 1.96	2.68***	1.79, 4.00
Walking one flight of stairs§	0.86	0.55, 1.36	1.46	0.83, 2.58
Bending, kneeling§	0.95	0.74, 1.22	2.17***	1.54, 3.06
Walking more than a mile§	1.33	0.98, 1.81	2.16***	1.44, 3.24
Walking several blocks§	1.26	0.84, 1.90	1.84*	1.08, 3.12
Walking one block§	0.86	0.53, 1.40	1.68	0.92, 3.04
Bathing or dressing§	1.15	0.65, 2.02	1.97	0.99, 3.92
'Poor' physical functioning concept#	1.36	0.88, 2.09	2.55***	1.51, 4.30

***P <0.001, **P <0.01, *P <0.05; †odds ratio with reference to body mass index <25; ‡systolic ≥160 or diastolic blood pressure ≥95 mmHg or medication for hypertension; §single items of physical functioning concept; #<66.7% standardised scores.

Table 6.1.4b. Odds ratios for chronic disease, symptoms and poor quality of life in categories of body mass index, adjusted for age and lifestyle factors (see **Appendix 6.1.1**), in women.

Women	Body mass index (kg/m^2)			
	25-30		≥30	
	OR†	95% CI	OR†	95% CI
Respiratory symptoms				
Wheezing when not having a cold	1.35**	1.11, 1.65	1.99***	1.55, 2.57
Woken up by shortness of breath	1.41**	1.23, 1.77	1.47**	1.08, 1.99
Coughing for more than 3 months	1.46***	1.89, 1.80	1.64***	1.25, 2.17
Bring up phlegm for more than 3 months	1.24	0.96, 1.60	1.69**	1.22, 2.34
Shortness of breath when walking uphill/stairs	1.61***	1.41, 1.83	3.27***	2.76, 3.89
Shortness of breath when walking with others	1.91***	1.54, 2.37	3.89***	3.04, 4.97
Cardiovascular risk factors				
High total cholesterol (≥6.5 mmol/l)	1.52***	1.29, 1.79	1.38**	1.10, 1.72
Low HDL-cholesterol (≤0.9 mmol/l)	1.67***	1.29, 2.17	2.30***	2.45, 4.44
Hypertension‡	1.95***	1.57, 2.43	4.75***	3.72, 6.07
At least one risk factor	1.72***	1.50, 1.97	2.87***	2.40, 3.43
Diabetes				
Non-insulin dependent diabetes mellitus	1.67	0.84, 3.31	5.38***	2.77, 10.46
Low back pain				
Chronic low back pain (total ≥12 weeks/year)	1.20**	1.05, 1.36	1.14	0.95, 1.37
Symptom of intervertebral disc hermiation	1.17*	1.01, 1.35	1.48***	1.22, 1.79
'Poor' quality of life				
Difficulties in physical functioning				
Vigorous activities§	1.35**	1.10, 1.67	2.06***	1.48, 2.87
Moderate activities§	1.52***	1.19, 1.92	1.48*	1.06, 2.07
Lift/carry groceries§	1.42**	1.14, 1.77	1.62**	1.19, 2.22
Walking several flights of stairs§	1.64***	1.28, 2.09	2.26***	1.63, 3.13
Walking one flight of stairs§	1.66**	1.16, 2.39	2.81***	1.83, 4.13
Bending, kneeling§	1.68***	1.34, 2.10	2.28***	1.67, 3.12
Walking more than a mile§	1.41**	1.08, 1.83	1.96***	1.39, 2.76
Walking several blocks§	1.47*	1.03, 2.09	2.38***	1.58, 3.63
Walking one block§	1.22	0.80, 1.87	2.36***	1.45, 3.83
Bathing or dressing§	0.80	0.43, 1.48	1.60	0.77, 3.30
'Poor' physical functioning concept#	1.61**	1.15, 2.24	2.41***	1.60, 3.63

***P <0.001, **P <0.01, *P <0.05; †odds ratio with reference to body mass index <25; ‡systolic ≥160 or diastolic blood pressure ≥95 mmHg or medication for hypertension; §single items of physical functioning concept; #<66.7% standardised scores.

Table 6.1.5. Prevalence of subjects whose daily life were affected due to low back pain in the past twelve months (n = 2467 men, 3448 women) in different categories of body mass index, adjusted for age, smoking and education.

	Men			Women		
	Body mass index (kg/m^2)			Body mass index (kg/m^2)		
	<25	25-30	≥30	<25	25-30	≥30
Proportions (%)†	(42.1)	(46.2)	(11.7)	(56.0)	(31.9)	(12.2)
Daily business hindered	28.2	27.4	34.9*	25.3	30.2**	32.3**
Absence from work	25.4	23.0	27.6	18.8	23.2*	28.4**
Medical consultation	39.3	40.9	40.5	39.6	44.7**	45.7**
Job redundancy	11.2	12.2	15.2	8.2	9.2	10.9
Job modification	8.7	8.3	8.7	7.0	7.7	3.2*

Difference from body mass index <25 kg/m^2: **P <0.01, *P <0.05; †proportions of subjects in each body mass index category.

Table 6.1.6a. Odds ratios of symptoms of chronic diseases and poor subjective health in different categories of body mass index, adjusted for age and lifestyle factors (see **Appendix 6.1.1**), in men.

Men	Body mass index			
	≥25		≥30	
	OR†	95% CI	OR††	95% CI
Respiratory symptoms	P = 0.560‡		P = 0.108‡	
Wheezing when not having a cold	1.22*	1.01, 1.48	1.39*	1.07, 1.82
Woken up by shortness of breath	1.07	0.84, 1.38	1.20	0.84, 1.69
Coughing for more than 3 months	0.97	0.78, 1.19	0.89	0.65, 1.24
Bring up phlegm for more than 3 months	1.01	0.81, 1.25	1.07	0.78, 1.47
Shortness of breath when walking uphill/stairs	1.76	1.50, 2.07	2.83***	2.34, 3.44
Shortness of breath when walking with others	1.50	1.13, 1.98	2.57***	1.9.1, 3.45
Cardiovascular risk factors	P = 0.560‡		P = 0.108‡	
High total cholesterol	1.69***	1.43, 2.00	1.67***	1.36, 2.04
Low HDL-cholesterol	2.62***	2.26, 3.03	2.88***	2.40, 3.46
Hypertension	3.42***	2.71, 4.31	2.79***	2.26, 3.45
At least one risk factor	2.75***	2.44, 3.10	3.25***	2.71, 3.89
Diabetes	P = 0.560‡		P = 0.108‡	
Non-insulin dependent diabetes mellitus	2.51***	1.42, 4.44	2.82***	1.78, 4.46
Symptoms of low back pain	P = 0.560		P = 0.108	
Chronic low back pain (total ≥12 weeks/year)	1.03	0.89, 1.19	1.03	0.83, 1.28
Symptom of intervertebral disc hermiation	1.13	0.96, 1.33	1.04	0.82, 1.30
'Poor' quality of life	P = 0.566‡		P = 0.112‡	
Difficulties in physical functioning				
Vigorous activities§	1.23*	1.00, 1.50	1.66**	1.21, 2.28
Moderate activities§	1.19	0.88, 1.62	1.27	0.85, 1.88
Lifting carrying groceries§	1.13	0.86, 1.49	1.37	0.96, 1.96
Walking several flights of stairs§	1.66***	1.24, 2.23	2.15***	1.51, 3.04
Walking one flight of stairs§	0.99	0.64, 1.52	1.60	0.97, 2.64
Bending, kneeling§	1.14	0.90, 1.44	2.23***	1.64, 3.05
Walking more than a mile§	1.49**	1.11, 1.98	1.82**	1.27, 2.60
Walking several blocks§	1.38	0.93, 2.04	1.59*	1.01, 2.52
Walking one block§	1.03	0.65, 1.61	1.83*	1.08, 3.09
Bathing or dressing§	1.32	0.78, 2.24	1.81*	1.01, 3.25
'Poor' physical functioning concept¶	1.60*	1.06, 2.40	2.10**	1.35, 3.26

***P <0.001, **P <0.01, *P<0.05; odds ratio with reference to body mass index group †below 25 and ††below 30 kg/m^2; ‡P = proportion of subjects 'exposed' to the risk of overweight; §single items of physical functioning concept; ¶<66.7% standardised scores.

Table 6.1.6b. Odds ratios of symptoms of chronic diseases and poor subjective health in different categories of body mass index, adjusted for age and lifestyle factors (see **Appendix 6.1.1**), in women.

Women	Body mass index			
	≥25		≥30	
	OR†	95% CI	OR††	95% CI
Respiratory symptoms	P = 0.419‡		P = 0.114‡	
Wheezing when not having a cold	1.52***	1.27, 1.82	1.75***	1.38, 2.22
Woken up by shortness of breath	1.44***	1.16, 1.77	1.25	0.94, 1.67
Coughing for more than 3 months	1.52***	1.25, 1.84	1.39*	1.07, 1.80
Bring up phlegm for more than 3 months	1.34***	1.08, 1.73	1.55**	1.15, 2.09
Shortness of breath when walking uphill/stairs	1.96***	1.74, 2.21	2.62***	2.23, 3.07
Shortness of breath when walking with others	2.40***	1.97, 2.92	2.81***	2.27, 3.48
Cardiovascular risk factors	P = 0.419‡		P = 0.114‡	
High total cholesterol	1.48***	1.27, 1.72	1.10	0.90, 1.35
Low HDL-cholesterol	2.11***	1.66, 2.67	2.56***	1.96, 3.33
Hypertension	2.59***	2.12, 3.17	3.31***	2.70, 4.07
At least one risk factor	1.98***	1.74, 2.24	2.21***	1.87, 2.61
Diabetes	P = 0.419‡		P = 0.114‡	
Non-insulin dependent diabetes mellitus	2.71***	1.48, 4.96	4.04***	2.41, 6.75
Symptoms of low back pain	P = 0.419‡		P = 0.114‡	
Chronic low back pain (total ≥12 weeks/year)	1.19**	1.05, 1.35	1.05	0.88, 1.26
Symptom of intervertebral disc hermiation	1.25**	1.09, 1.42	1.38***	1.15, 1.64
'Poor' quality of life	P = 0.395‡		P = 0.106‡	
Difficulties in physical functioning				
Vigorous activities§	1.50***	1.23, 1.81	1.84***	1.33, 2.53
Moderate activities§	1.51***	1.21, 1.88	1.24	0.90, 1.70
Lifting carrying groceries§	1.47***	1.20, 1.80	1.40*	1.04, 1.90
Walking several flights of stairs§	1.79***	1.43, 2.24	1.82***	1.34, 2.48
Walking one flight of stairs§	1.97***	1.42, 2.74	2.20***	1.50, 3.24
Bending, kneeling§	1.82***	1.48, 2.24	1.83***	1.36, 2.47
Walking more than a mile§	1.55***	1.22, 1.96	1.69*	1.22, 2.33
Walking several blocks§	1.71***	1.25, 2.35	2.00***	1.36, 2.95
Walking one block§	1.53**	1.05, 2.22	2.16***	1.39, 3.36
Bathing or dressing§	1.00	0.59, 1.70	1.75	0.88, 3.46
'Poor' physical functioning concept¶	1.82***	1.34, 2.47	1.94***	1.33, 2.82

***P <0.001, **P <0.01, *P<0.05; odds ratio with reference to body mass index group †below 25 and ††below 30 kg/m^2; ‡P = proportion of subjects 'exposed' to the risk of overweight; §single items of physical functioning concept; ¶<66.7% standardised scores.

Table 6.1.7. Population attributable risks of ill health due to overweight.

	Population attributable risk (%)			
	Men		Women	
	≥25*	≥30**	≥25*	≥30**
Respiratory symptoms				
Wheezing when not having a cold	11.0	4.0	17.9	7.8
Woken up by shortness of breath	3.8	2.1	15.6	2.8
Coughing for more than 3 months	NA	NA	17.9	4.3
Bring up phlegm for more than 3 months	0.6	0.8	12.5	5.9
Shortness of breath when walking uphill/stairs	29.9	16.5	28.7	15.6
Shortness of breath when walking with others	21.9	14.5	37.0	17.1
Cardiovascular risk factors				
High total cholesterol	27.9	6.8	16.7	1.1
Low HDL-cholesterol	47.6	16.9	31.7	15.1
Hypertension	57.5	16.2	40.0	20.8
At least one risk factor	49.5	19.6	29.1	12.1
Diabetes				
Non-insulin dependent diabetes mellitus	45.8	16.4	41.7	25.7
Symptoms of low back pain				
Chronic low back pain (total ≥12 weeks/year)	1.7	0.3	7.4	0.6
Symptom of intervertebral disc herniation	6.8	0.4	9.5	4.2
Poor' quality of life				
Difficulties in physical functioning†				
Vigorous activities†	11.5	6.9	16.5	8.2
Moderate activities†	9.7	2.9	16.8	2.5
Lifting carrying groceries†	6.9	4.0	15.7	4.1
Walking several flights of stairs†	27.2	11.4	23.8	8.0
Walking one flight of stairs†	NA	6.3	27.7	11.3
Bending, kneeling†	7.3	12.1	24.5	8.1
Walking more than a mile†	21.7	8.4	17.9	6.8
Walking several blocks†	17.7	6.2	21.9	9.6
Walking one block†	1.7	8.5	17.3	11.0
Bathing or dressing†	15.3	8.3	0.0	7.4
'Poor' physical functioning concept‡	25.4	11.0	24.5	9.1

NA = not applicable as OR <1; reference group with body mass index *below 25 and **below 30 kg/m^2; †single items of physical functioning concept; ‡<66.7% standardised scores.

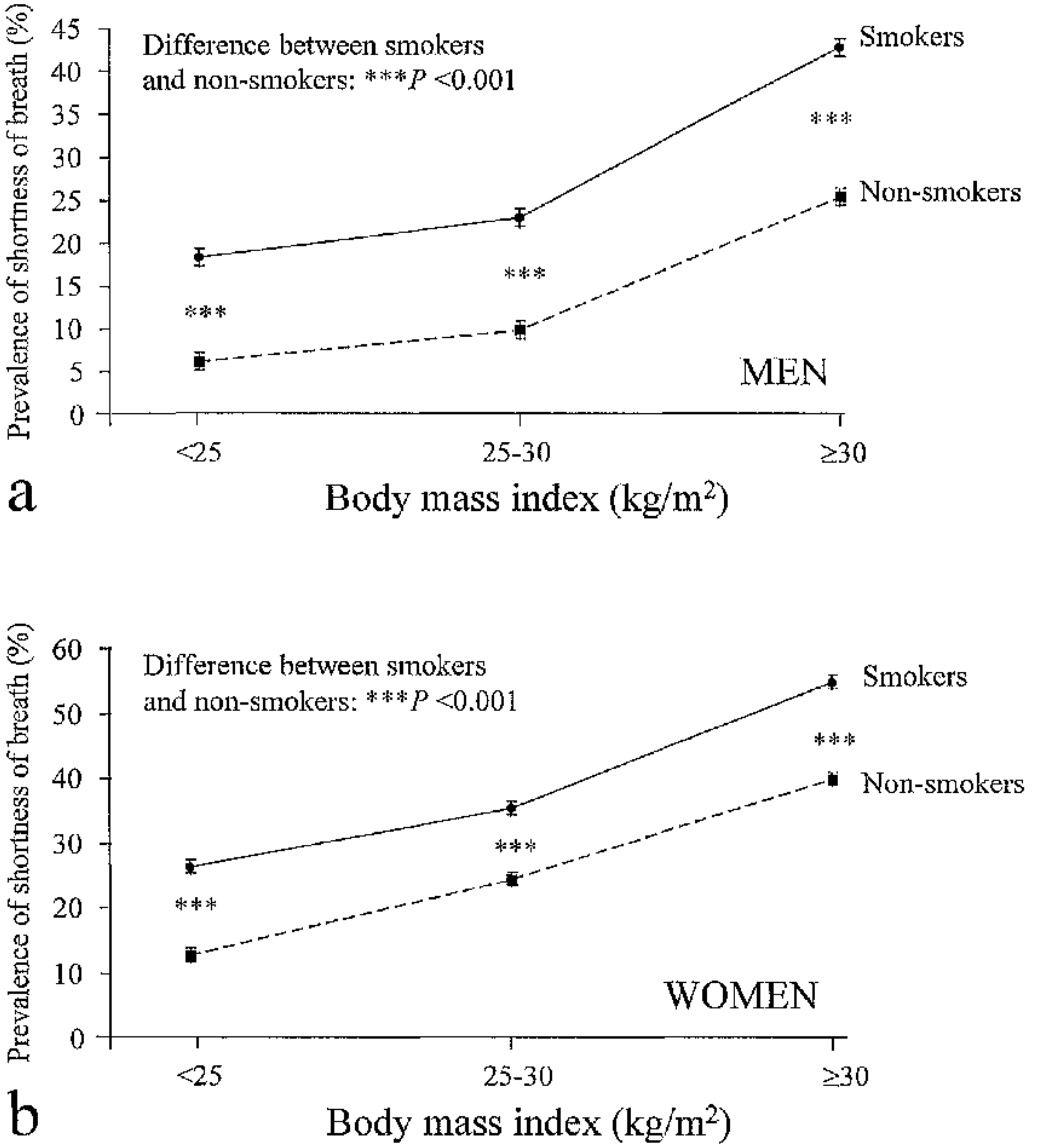


Figure 6.1.1. Age adjusted prevalence of shortness of breath when walking uphill or upstairs in smokers and non-smokers in different categories of body mass index based on the WHO (1995) standard cut-offs, in men (a) and in women (b).

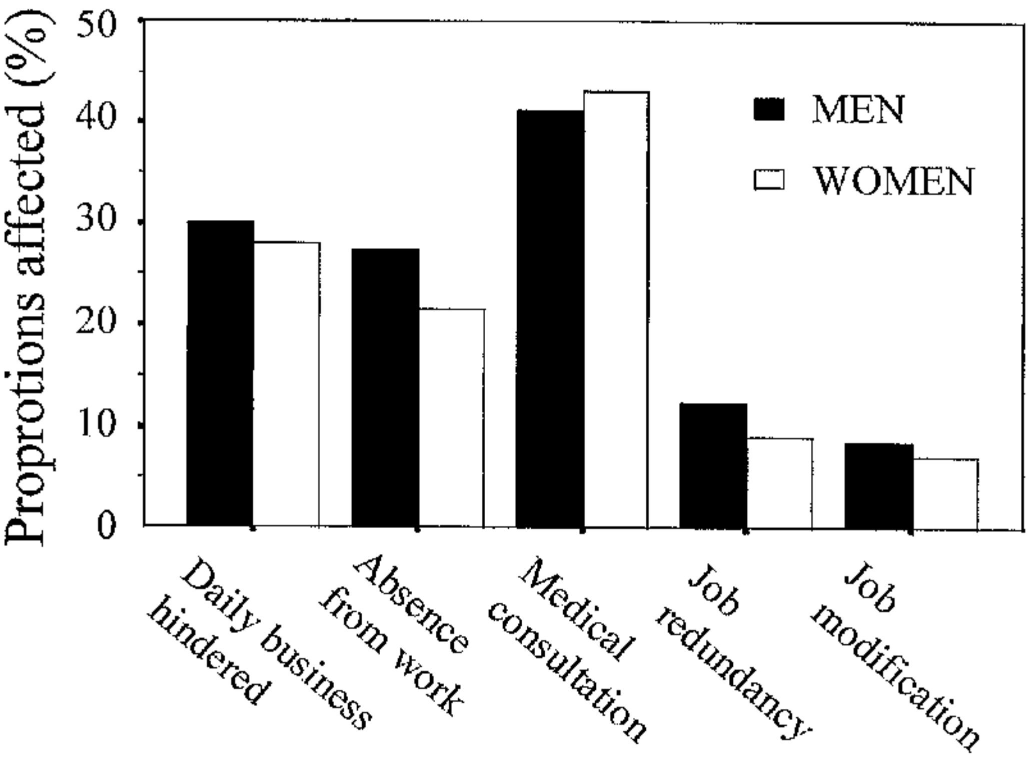


Figure 6.1.2. The proportions of subjects whose daily activities were affected by low back pain in the past twelve months.

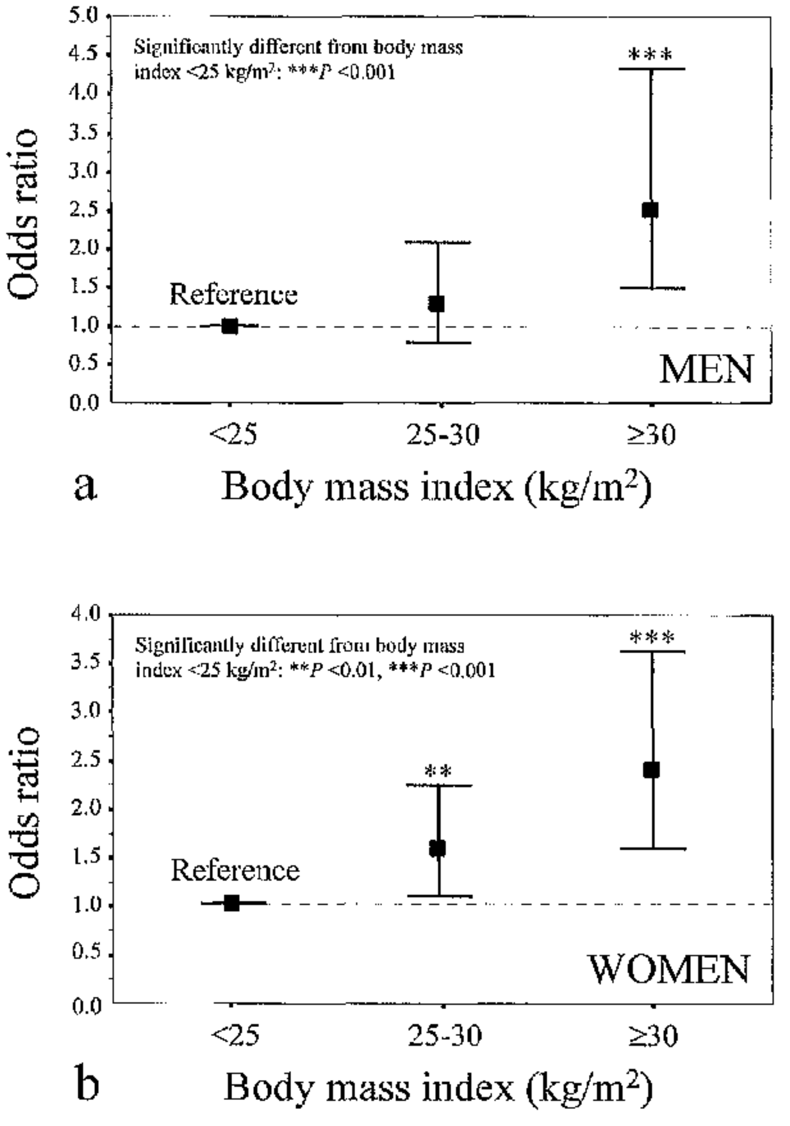


Figure 6.1.3. Odds ratios for poor physical functioning (standardised scores <66.7%) in men (a) and women (b) in different categories of body mass index based on the standard WHO (1995) cut-offs. Odds ratios adjusted for age, lifestyle and demographic factors.

Appendix 6.1.1. Age, lifestyle and demographic factors as possible confounders considered in analysis of the associations of symptoms of chronic disease and impaired quality of life with body mass index.

	Reference group	Dummy variables		
		1	2	3
Age (years)[a,b,c,d,e]	20-29	30-39	40-49	50-59
Smoking[a,b,c,d,e]	Non-smokers	Ex-smokers	Current smokers	
Alcohol consumption (glasses/day)[a,b,c,e]	Occasional (<1)	None (0)	Moderate (1 to <3)	Heavy (≥3)
Physical activity[a,b,c,e]	Active (do sport)	Inactive (do no sport)		
Educational level[a,b,c,d,e]	Level 3 (higher vocational or university)	Level 2 (vocational or higher secondary)	Level 1 (lower than secondary)	
Marital status[e]	Single	Married or cohabiting	Divorced or widowed	
Employment[e]	Currently employed	Unemployed	Housewives	Retired early
Household composition[e]	Living with someone	Living with no one		
Intimate contact†[e]	No one	1-2	3-5	≥6
Parity (live births)[e]	None	1-2	≥3	

Factors corrected for in logistic regression analysis: [a]respriatory symptoms, [b]cardiovascular risk factors, [c]diabetes, [d]low back pain, and [e]quality of life; †discussing personal matters with other people.

— 6.2 —

IMPAIRMENT OF HEALTH AND QUALITY OF LIFE FROM ABDOMINAL FAT ACCUMULATION, USING WAIST CIRCUMFERENCE 'ACTION LEVEL'

This section has been submitted for publication as

Han TS, Lean MEJ, Seidell JC. Impairment of health and quality of life from abdominal fat accumulation, using waist circumference Action Levels. (submitted).

Collaboration with MORGEN project

ABSTRACT

Objective: To estimate the prevalence and risks of chronic disease, secondary symptoms and poor quality of life associated with waist circumference, using standardised cut-offs.

Design: Cross-sectional study in a random sample set in the Netherlands.

Subjects: 5887 men and 7018 women aged 20-59 years selected from the civil registry of Amsterdam, Maastricht and Doetinchem.

Main outcome measures: Symptoms of respiratory insufficiency, low back pain, non-insulin-dependent diabetes, cardiovascular risk factors, and physical functioning.

Results: People with waist below Action Level 1 (<94 cm in men, <80 cm in women) were considered the reference population with low prevalence of symptoms of obesity related diseases and good subjective health. Between Action Level 1 and Action Level 2: 94-102 cm in men, 80-88 cm in women), the prevalence of these all increase, and above Action Level 2 (≥102 cm in men, ≥88 cm in women) greatly increased. After adjustments for age and lifestyle factors, odds ratios (95% confidence intervals) in those with a waist above Action Level 2 were 3.1 (2.5 to 3.7) in men and 2.7 (2.3 to 3.1) in women for shortness of breath when walking upstairs, 4.5 (2.5 to 7.8) in men and 3.8 (1.9 to 7.3) in women for non-insulin-dependent diabetes, 4.2 (3.6 to 5.0) in men and 2.8 (2.4 to 3.2) in women for at least one major cardiovascular risk factor. Both men and women with waist above Action Level 2 were twice more likely to have difficulties in performing a range of basic activities of daily living. Women with waist above Action Level 2 were 1.5 times more likely to have low back pain for a total ≥12 weeks a year or symptoms of intervertebral disc herniation, and significantly more of them had problems associated with low back pain including hindrance to their daily business, absence from work, medical consultation, and job redundancy. The calculated population attributable risks to estimate the excess risk of ill health attributable to waist above the Action Levels were between 10-40%.

Conclusions: Symptoms and secondary diseases related to large waist share a huge health care expenditure, demanding major health promotion programme. The data justify the employment of Action Levels of waist circumference for health promotion.

INTRODUCTION

National health burdens are aggravated by clusters of secondary symptoms associated with overweight and adverse fat distribution, including coronary heart disease, strokes, non-insulin dependent diabetes mellitus (NIDDM), and several cancers. Recent estimates costs per annum for treating this ill health were 195 million pounds in Britain (Office of Health Economics, 1994), and 70 billion dollars in the United States (Institute of Medicine, 1995). These figures present major concerns to the health service, since the prevalence of overweight is still rising in many countries (Kuczmarski, 1992, Seidell 1995a; Bennett *et al*, 1995; Gregory *et al*, 1990).

From the ongoing MORGEN project (monitoring cardiovascular health in The Netherlands), we have shown that waist circumference, body mass index and waist to hip ratio all relate closely and similarly to a variety of symptoms of chronic diseases (**Chapter 5**). For the purpose of public health promotion, Action Levels of waist circumference, based on body mass index and waist to hip ratio have been derived as a simpler method of risk assessment than by attempting to combine these two rather complex indices (**Chapter 3.1**; Lean *et al*, 1995). Waist does not need to adjusted for height as an index of adiposity and fat distribution (**Chapter 4.3**; Han *et al*, 1997c), although height may have separate association with health.

The present study summarised the risks of symptoms from major chronic diseases and of poor subjective health in relation to waist circumference categories based on the previously derived Action Levels (**Chapter 3.1**; Lean *et al*, 1995).

METHODS

Subjects

Dutch men (n = 5887) and women (n = 7018) aged 20-59 were recruited randomly from civil registries for the ongoing MORGEN (Monitoring Risk Factors and Health in The Netherlands) project 1993 to 1995 cohorts, from Amsterdam, Maastricht, and Doetinchem. To obtain similar numbers of subjects at each age, the sample was stratified by sex and five year age group. The response rate to invitations was about 50%. Information on quality of life was available in the 1995 cohort of 1885 men and 2156 women. The numbers of subjects in the present study represent those who attended the health centres for biochemical and physiological measurements.

Measurements

All measurements and questionnaire assessment were performed by trained paramedical personnel. Waist circumference was measured in duplicate at the level between the lowest rib margin and iliac crest (WHO, 1995).

Symptoms of disease

Major symptoms and diseases associated with overweight were selected from our previous studies (**Chapter 5**). Symptoms of respiratory insufficiency included shortness of breath, wheezing, coughing and bringing up phlegm (**Chapter 5.4**). Risk factors for cardiovascular disease included hypercholesterolaemia (plasma total cholesterol ≥6.5 mmol/l), low high density lipoprotein cholesterol (≤0.9 mmol/l) and hypertension (systolic blood pressure ≥160 mmHg and/or diastolic blood pressure ≥95 mmHg and/or the use of antihypertensive agent) (**Chapter 5.2**; Han *et al*, 1995c). Known and newly diagnosed (random blood glucose ≥11.1 mmol/l) NIDDM were included, and insulin treated patients were excluded as indistinguishable from insulin dependent diabetes mellitus (**Chapter 5.5**; Seidell *et al*, 1997). Symptoms of low back pain were obtained from questionnaire. Those who responded affirmatively to having *low back pain in the past 12 months*, were then asked whether they had radiating pain to the knees or feet, to indicate *symptoms of intervertebral disc herniation*. This symptom was only accepted in the presence of low back pain, to avoid including those with other causes of radiated pain. The subjects were asked about the total duration of low back pain in the past 12 months. Those who had low back pain for a total of twelve weeks or more were classified as having *chronic low back pain*. The *reference groups* for the three classes of low back pain were composed of those who did not fulfil the criteria for the symptom under analysis, thus the reference group when analysing one symptom included some subjects with other symptom(s) of low back pain (**Chapter 5.3**; Han *et al*, 1997d). From *ten items* rated by subjects using the standardised Dutch RAND-36 questionnaire, which has been adapted from the standardised SF-36 Health Survey the concept of physical functioning, was calculated to represent quality of life. Distributions of standardised scores were examined from the plots (not shown) to determine arbitrary cut-offs for the health concepts. It was decided arbitrarily that subjects with *less than 66.7% of the standardised score* would be classified as having a '*poor' health concept*, and those with *66.7% or above* were considered as having a *'good' health concept.* This cut-off classified 8.4% of all men and 10.8% of all women as having 'poor' physical functioning. Each of the ten items comprising the physical functioning health concept was arbitrarily dichotomised such that scores above average (with an odd numbered scale of 3 or 5 points) were considered as '*good' health*, and average or lower scores were classed as '*poor' health.* For items with *even scale* (2, 4 or 6 points), the scores for '*good' health* and '*poor' health* were evenly divided (**Chapter 5.6**).

Lifestyle and demographic factors as confounding factors

Dummy variables (**Appendix 6.2.1**) for possible confounding factors were created to adjust for the associations between adiposity and health concepts and individual items.

Statistical methods

Statistical analyses were performed using SAS version 6.1 (Cary, USA). Logistic regression analysis was used to estimate the odds ratios and 95% confidence intervals of symptoms of disease and 'poor' quality of life in those with waist circumference in the categories of between 'Action Level 1 and Action Level 2 (94-102 cm in men and 80-88 cm in women) or above Action Level 2 (≥102 cm in men and ≥88 cm in women), compared to those with waist below Action Level 1 (<94 cm in men and <80 cm in women), adjusted for age, lifestyle and demographic factors (**Appendix 6.2.1**).

Population attributable risks

The population attributable risk, i.e. the proportionate excess risk of ill health associated with exposure to the risk of large waist based the waist circumference Action Level 1 cut-off (PAR_{AL1}) was calculated as (Kahn and Sempos, 1989; Kleinbaum *et al*, 1982):

$$PAR_{AL1} = P_{AL1} \times (OR_{AL1} - 1)/[P_{AL1} \times (OR_{AL1} - 1)] + 1,$$

where P_{AL1} is the proportion of subjects exposed to the risk of large waist circumference, i.e. all subjects with waist above Action Level 1, OR_{AL1} is the age and lifestyle adjusted odds ratio for a symptom or disease in subject group with waist above Action Level 1 compared to the reference group with waist below Action Level 1. Population attributable risk using waist circumference cut-off at Action Level 2 (PAR_{AL2}) was calculated the same way, with the proportion of subjects exposed to waist above Action Level 2, and the odds ratios for a disease in subjects with waist above Action Level 2 compared to the reference group with waist below Action Level 2. The difference between PAR_{AL1} and PAR_{AL2} gives $PAR_{AL1\text{-}AL2}$ for waist circumference between Action Levels 1 and 2. This equation is valid only when the odds ratio is equal or greater than 1.

RESULTS

Characteristics of all subjects studied from 1993 to 1995 are shown in **Table 6.2.1**. The characteristics were similar each year's cohort and are described elsewhere (**Chapter 5**).

The number of subjects and the overall prevalence for each symptom studied are presented in **Table 6.2.2**. The prevalence of symptoms and 'poor' quality of life rose with increasing waist circumference (**Table 6.2.3**). After adjustments for age and appropriate lifestyle factors, compared to those with waist below Action Level 1, those with waist above Action Level 2 were several times more likely to be at risk of poor health (**Tables 6.2.4a & b**).

Figures 6.2.1a & b show that within separate groups of non-smokers and smokers, the prevalence of those with shortness of breath when walking uphill or upstairs increased with increasing BMI, and significantly (P <0.001) higher in smokers for each level of waist circumference. **Figure 6.2.2** shows the proportions of subjects whose daily life activities were affected by low back pain. About a third of men and women reported that, due to low back pain, their daily business was hindered, they had to be absent from work, and more than forty percent sought medical consultation as a result of low back pain. **Table 6.2.5** shows that after adjustments for age and lifestyle factors, the proportions of these consequences of low back pain were significantly higher in women with waist circumference above Action Level 2 compared to women below Action Level 1. The proportion of job redundancy due to low back pain was significantly higher in men with waist circumference above Action Level 2 compared to men below Action Level 1. Those with large waist circumference had lower scores for physical functioning (**Figure 6.2.3**) and the odds ratios (95% confidence interval limits) for 'poor' physical function health concept were two and half times higher in subjects with waist circumference above Action Level 2 compared to those below Action Level 1.

Tables 6.2.6 a & b show the proportions of subjects 'exposed' to large waist, with waist above Action Level 1 or Action Level 2, and the odds ratios for ill health. These values were used to calculate the population attributable risks for symptoms of disease and 'poor' quality of life in those with waist circumference above Action Level 1 or above Action Level 2. The difference in population attributable risks between categories above Action Level 1 and above Action Level 2 is the population attributable risks for those with a waist circumference in between the two Action Levels.

Tables 6.2.6 a & b show the proportions of subjects 'exposed' to large waist, with waist circumference above Action Level 1 or Action Level 2, and the odds ratios for ill health. These values were used to calculate the population attributable risks for symptoms of disease and 'poor' quality of life in those with waist above Action Level 1 or Action Level 2. **Table 6.2.7** shows that the excess proportions of subjects with poor health attributable to large waist (above Action Level 1) were approximately 10 to 40 percent. The difference in population attributable risks from categories of waist circumference Action Levels 1 and 2 is the population attributable risk for those with a waist between

Action Level 1 to Action Level 2. This difference of population attributable risk was as high as the values for category above Action Level 2.

DISCUSSION

Body mass index has become the conventional index for classifying adiposity (WHO, 1995), and we have analysed the present data set using conventional BMI cut-offs (**Chapter 6.1**). On the other hand, BMI is not a perfect index, since it still has some relationship with height (**Chapter 4.3**; Han *et al*, 1997c) and BMI fails to take account of fat distribution in its relationship with ill health. Waist circumference is an alternative measure with some advantages. It is now recognised that adverse central fat distribution has a separate impact on similar health problems as overweight. The present study examined the relationships between several chronic diseases and quality life with waist circumference, which reflects both BMI and central fat deposition (**Chapter 3.1**; Lean *et al*, 1995). We have already shown that those with large waist (i.e. highest tertile) are at several times more at risk of symptoms of disease and having difficulty in perform basic daily activities, as assessed by quality of life (**Chapter 5.6**).

The present study has brought together data from analyses, several health associations and has applied standardised cut-off of waist circumference which we have previously defined as representing Action Levels for health promotion. Using waist circumference cut-offs, some 20% of adults exceed Action Level 2, and can be seen to need weight management. These include 90% of those with BMI $\geq$30 kg/m^2 and also those with BMI 25-30 who also have central fat distribution (**Chapter 3.1**; Lean *et al*, 1995). Chan *et al* (1994) have shown that compared to men in the lowest 20% of waist circumference (<34.5 inches), men in the top 20% of waist circumference ($\geq$40 inches) had age and lifestyle adjusted relative risk of 11 (95% confidence interval: 6 to 19) for developing NIDDM in a five year follow-up survey. This top quintile cut-off coincides with our Action Level 2. Standard cut-offs based on the Action Levels allow comparisons between studies, such as population attributable risks (**Table 6.2.6**) to highlight the excessive costs of adverse fat distribution in different populations.

Health Economic evaluations of overweight has been hampered by lack of consistent analyses using standardised criteria, and particularly criteria for the reference population. There is an additional practical problem in the need for accurate, calibrated equipment to measure height and weight in surveys. Given that waist circumference does not vary importantly with height as an index of adiposity (**Chapter 4.3**; Han *et al*, 1997c), there are practical attractions to its use in health surveys.

In the present study, there were 24% men and 18% women with waist circumference above Action Level 2, who clearly had increased health problems of all kinds. There was also a significant, intermediate element of risk for those with waist circumference between Action Level 1 and Action Level 2 for many health problems. In this regard, waist circumference cut-offs can be seen to perform at least as well as the corresponding BMI cut-offs (25-30, ≥30 kg/m^2). The grades of risk are similar for waist above Action Level 2 and BMI above 30 kg/m^2 in both men and women for all the outcome measures. On the other hand, the range Action Level 1 to Action Level 2 several significant impairments of physical function in men, but not women whereas BMI 25-30 kg/m^2 was associated with significantly impaired physical function in women but not in men. Odds ratios are likely to be overestimated if the prevalence is high (Lee, 1994). Thus the results of some items of the physical functioning health concept (**Tables 6.2.3a & b**) in the present study should be interpreted with caution.

It is important that those with waist circumference above Action Level 2 should be urged to undergo screening for metabolic risks including hypertension, dislipidaemia and particularly NIDDM. It is a common knowledge that most people who have NIDDM are unaware of it (Harris *et al*, 1992), even with complications (UKPDS Group, 1990). **Table 6.2.7** shows the population attributable risks based on waist circumference

Action Level 1 and Action Level 2, providing standard values for estimating excess costs of ill health due to overweight.

CONCLUSIONS

There is no strong *a priori* reason to prefer BMI or waist circumference for categorising adiposity or predict preventable ill health. There are some minor differences in the patterns of disease and symptoms associated with intermediate categories of BMI or waist circumference, but above Action Level 2 or BMI 30 kg/m^2, a wide range of problems will have developed in a large population of adults. The greater number above Action Level 2 (20% of adults) than above BMI 30 kg/m^2 (15%) reflects those with central fat distribution which BMI still in the range 25-30 kg/m^2. The aims of health promotion and of effective long term treatment should be to prevent progression into the highest categories, very substantial reductions in health care costs and social costs are likely if that is achieved.

Table 6.2.1. Characteristics of 5887 men and 7018 women.

	Men			Women		
	Mean	SD	Range	Mean	SD	Range
Age (years)	42.9	10.7	20.3-60.0	42.2	11.0	20.2-59.9
Weight (kg)	82.0	12.0	44.4-157.0	68.5	11.5	36.6-153.0
Height (cm)	178.4	7.3	152.0-210.0	165.7	6.7	134.5-190.0
Body mass index (kg/m^2)	25.8	3.5	15.7-50.1	25.0	4.2	14.9-58.3
Waist circumference (cm)	92.3	10.8	64.0-155.0	81.0	11.1	56.5-150.0
Hip circumference (cm)	101.8	6.6	69.0-150.0	102.2	8.4	76.4-165.0
Waist to hip ratio	0.905	0.072	0.621-1.369	0.791	0.070	0.567-1.302

Table 6.2.2. Unadjusted prevalence in total population of 5887 men and 7018 women (1885 men and 2156 women had information on quality of life) with chronic disease, symptoms and poor quality of life.

	Men		Women	
	%	95% CI	%	95% CI
Respiratory symptoms				
Wheezing when not having a cold	9.2	8.5, 10.0	8.4	7.7, 9.2
Woken up by shortness of breath	5.0	4.4, 5.6	6.1	5.5, 6.7
Coughing for more than 3 months	7.7	7.0, 8.4	7.5	6.8, 8.2
Bring up phlegm for more than 3 months	6.8	6.2, 7.5	5.0	4.3, 5.6
Shortness of breath when walking uphill/stairs	16.0	15.1, 17.0	24.7	23.7, 25.6
Shortness of breath when walking with others	4.6	4.0, 5.1	7.4	6.9, 7.9
Cardiovascular risk factors				
High total cholesterol (≥6.5 mmol/l)	14.6	13.7, 15.5	13.5	12.7, 14.3
Low HDL-cholesterol (≤0.9 mmol/l)	21.3	20.3, 22.3	5.1	4.6, 5.6
Hypertension*	10.3	9.5, 11.1	8.3	7.7, 8.9
At least one risk factor	38.0	36.8, 39.2	23.5	22.5, 24.5
Diabetes				
Non-insulin dependent diabetes mellitus	1.6	1.3, 1.9	0.9	0.7, 1.2
Symptoms of low back pain				
Chronic low back pain (total ≥12 weeks/year)	16.6	15.6, 17.6	20.5	19.6, 21.4
Symptoms of intervertebral disc hermiation	13.4	12.5, 14.3	17.6	16.7, 18.4
'Poor' quality of life				
Difficulties in physical functioning				
Vigorous activities†	50.1	47.8, 52.4	54.0	51.7, 56.3
Moderate activities†	13.7	12.1, 15.3	24.1	22.5, 25.7
Lifting/carrying groceries†	17.5	15.8, 19.3	32.6	30.8, 34.3
Walking several flights of stairs†	15.8	14.1, 17.4	22.2	20.5, 23.9
Walking one flight of stairs†	6.4	5.2, 7.5	8.9	7.8, 10.0
Bending, kneeling†	25.4	23.4, 27.4	28.2	26.2, 30.2
Walking more than a mile†	15.2	13.5, 16.8	18.4	16.7, 20.0
Walking several blocks†	8.0	6.8, 9.3	9.4	8.2, 10.7
Walking one block†	5.5	4.4, 6.5	6.5	5.4, 7.5
Bathing or dressing†	4.0	3.1, 4.9	3.1	2.2, 4.0
'Poor' physical functioning concept‡	8.4	7.2, 9.7	10.8	9.5, 12.0

*Systolic ≥160 or diastolic blood pressure ≥95 mmHg or medication for hypertension; †single items of physical functioning concept; ‡<66.7% standardised scores.

Table 6.2.3a. Unadjusted prevalence of subjects with chronic disease, symptoms and poor quality of life in categories of waist circumference Action Levels, in men.

Men	Waist circumference (cm)			
	<94	94-102	≥102	χ^2
Proportions of subjects	*(57.9)*	*(24.1)*	*(18.0)*	
Respiratory symptoms				
Wheezing when not having a cold	8.5	9.1	11.9	11.3**
Woken up by shortness of breath	4.3	5.7	6.4	9.6**
Coughing for more than 3 months	7.2	8.2	8.8	3.4
Bring up phlegm for more than 3 months	6.3	7.2	8.0	4.1
Shortness of breath when walking uphill/stairs	10.4	17.1	31.5	261***
Shortness of breath when walking with others	2.8	4.7	10.0	97.1***
Cardiovascular risk factors				
High total cholesterol (≥6.5 mmol/l)	9.5	18.0	26.4	202.5***
Low HDL-cholesterol (≤0.9 mmol/l)	15.3	26.5	33.5	192.1***
Hypertension†	4.7	12.3	25.3	382.8***
At least one risk factor	26.0	47.4	64.2	571.4***
Diabetes				
Non-insulin dependent diabetes mellitus	0.6	1.8	4.5	82.8***
Low back pain				
Chronic low back pain (total ≥12 weeks/year)	14.1	19.5	21.1	39.8***
Symptom of intervertebral disc hermiation	11.1	16.5	16.5	37.3***
'Poor' quality of life				
Difficulties in physical functioning				
Vigorous activities‡	42.2	59.9	62.6	66.4***
Moderate activities‡	10.2	16.3	21.3	30.7***
Lift/carry groceries‡	13.7	20.2	26.2	31.3***
Walking several flights of stairs‡	10.4	17.9	29.9	77.6***
Walking one flight of stairs‡	4.7	5.7	12.6	28.8***
Bending, kneeling‡	18.7	28.6	42.5	82.1***
Walking more than a mile‡	10.8	18.1	25.0	45.8***
Walking several blocks‡	4.9	9.3	16.1	46.0***
Walking one block‡	3.8	5.2	10.9	25.8***
Bathing or dressing‡	2.7	4.1	8.1	19.2***
'Poor' physical functioning§	4.8	10.2	17.5	57.4***

***P <0.001, **P <0.01, *P <0.05; †systolic ≥160 or diastolic blood pressure ≥95 mmHg or medication for hypertension; ‡single items of physical functioning concept; §<66.7% standardised scores.

Table 6.2.3b. Unadjusted prevalence of subjects with chronic disease, symptoms and poor quality of life in categories of waist circumference Action Levels, in women.

Women	Waist circumference (cm)			χ^2
	<80	80-88	≥88	
Proportions of subjects	*(51.7)*	*(24.4)*	*(23.9)*	
Respiratory symptoms				
Wheezing when not having a cold	7.1	8.5	11.3	27.2***
Woken up by shortness of breath	4.8	6.9	8.2	25.8***
Coughing for more than 3 months	6.3	7.5	10.3	27.2***
Bring up phlegm for more than 3 months	4.3	4.4	6.9	18.0***
Shortness of breath when walking uphill/stairs	17.4	25.5	39.4	300***
Shortness of breath when walking with others	4.5	7.9	14.6	166***
Cardiovascular risk factors				
High total cholesterol (≥6.5 mmol/l)	8.0	16.6	22.4	222.7***
Low HDL-cholesterol (≤0.9 mmol/l)	3.2	4.4	9.9	108.7***
Hypertension†	3.2	7.6	19.9	414.8***
At least one risk factor	13.6	26.0	42.5	540.7***
Diabetes				
Non-insulin dependent diabetes mellitus	0.4	0.5	2.7	72.1***
Low back pain				
Chronic low back pain (total ≥12 weeks/year)	16.5	22.8	26.9	83.3***
Symptom of intervertebral disc hermiation	14.4	18.0	24.1	75.7***
'Poor' quality of life				
Difficulties in physical functioning				
Vigorous activities‡	46.9	55.2	68.8	68.8***
Moderate activities‡	17.6	24.9	37.8	79.8***
Lift/carry groceries‡	25.2	33.5	48.0	83.5***
Walking several flights of stairs‡	16.2	22.3	35.7	78.1***
Walking one flight of stairs‡	5.6	8.4	16.8	54.7***
Bending, kneeling‡	19.6	28.3	47.4	135***
Walking more than a mile‡	14.0	18.9	27.7	44.5***
Walking several blocks‡	6.9	8.2	16.2	36.8***
Walking one block‡	4.8	5.4	11.1	24.5***
Bathing or dressing‡	2.8	3.0	3.9	1.5
'Poor' physical functioning§	7.1	10.0	19.7	59.1***

***P <0.001, **P <0.01, *P <0.05; †systolic ≥160 or diastolic blood pressure ≥95 mmHg or medication for hypertension; ‡single items of physical functioning concept; §<66.7% standardised scores.

Table 6.2.4a. Odds ratios for chronic disease, symptoms and poor quality of life in categories of waist Action Levels, adjusted for age and lifestyle factors (see **Appendix 6.2.1**), in men.

Men	Waist circumference			
	94-102		≥102	
	OR†	95% CI	OR†	95% CI
Respiratory symptoms				
Wheezing when not having a cold	1.10	0.88, 1.40	1.42**	1.11, 1.80
Woken up by shortness of breath	1.22	0.91, 1.64	1.29	0.94, 1.77
Coughing for more than 3 months	1.14	0.89, 1.45	1.11	0.85, 1.45
Bring up phlegm for more than 3 months	1.07	0.83, 1.38	1.10	0.83, 1.46
Shortness of breath when walking uphill/stairs	1.50***	1.24, 1.81	3.05***	2.53, 3.67
Shortness of breath when walking with others	1.37	0.98, 1.91	2.67***	1.96, 3.64
Cardiovascular risk factors				
High total cholesterol (≥6.5 mmol/l)	1.55***	1.28, 1.86	2.35***	1.94, 2.85
Low HDL-cholesterol (≤0.9 mmol/l)	2.29***	1.95, 2.70	3.28***	2.75, 3.92
Hypertension‡	2.00***	1.59, 2.52	4.29***	3.43, 5.36
At least one risk factor	2.24***	1.95, 2.57	4.23***	3.61, 4.95
Diabetes				
Non-insulin dependent diabetes mellitus	2.04*	1.11, 3.76	4.45***	2.54, 7.79
Low back pain				
Chronic low back pain (total ≥12 weeks/year)	1.16	0.97, 1.37	1.17	0.97, 1.41
Symptom of intervertebral disc hermiation	1.22*	1.01, 1.37	1.12	0.91, 1.37
'Poor' quality of life				
Difficulties in physical functioning				
Vigorous activities§	1.59***	1.25, 2.03	1.59***	1.21, 2.09
Moderate activities§	1.34	0.95, 1.90	1.57*	1.09, 2.26
Lift/carry groceries§	1.20	0.88, 1.65	1.46*	1.05, 2.03
Walking several flights of stairs§	1.47*	1.05, 2.06	2.60***	1.85, 3.63
Walking one flight of stairs§	0.88	0.51, 1.49	1.82*	1.23, 2.94
Bending, kneeling§	1.31*	1.00, 1.73	2.26***	1.69, 3.01
Walking more than a mile§	1.67**	1.20, 2.32	2.28***	1.62, 3.22
Walking several blocks§	1.62*	1.03, 2.56	2.63***	1.69, 4.11
Walking one block§	1.18	0.67, 2.06	2.31**	1.38, 3.86
Bathing or dressing§	1.24	0.66, 2.33	2.21**	1.23, 3.99
'Poor' physical functioning#	1.75*	1.10, 2.78	2.78***	1.77, 4.38

***P <0.001, **P <0.01, *P <0.05; †odds ratio with reference to waist circumference <94 cm (below Action Level 1); ‡systolic ≥160 or diastolic blood pressure ≥95 mmHg or medication for hypertension; §single items of physical functioning concept; #<66.7% standardised scores.

Table 6.2.4b. Odds ratios for chronic disease, symptoms and poor quality of life in categories of waist circumference Action Levels, adjusted for age and lifestyle factors, in women (see **Appendix 6.2.1**).

Women	Waist circumference Action Levels			
	80-88		≥88	
	OR†	95% CI	OR†	95% CI
Respiratory symptoms				
Wheezing when not having a cold	1.23	0.99, 1.53	1.64***	1.32, 2.04
Woken up by shortness of breath	1.47**	1.14, 2.15	1.67***	1.30, 2.15
Coughing for more than 3 months	1.19	0.94, 1.50	1.56***	1.24, 1.97
Bring up phlegm for more than 3 months	0.97	0.72, 1.30	1.46**	1.11, 1.92
Shortness of breath when walking uphill/stairs	1.52***	1.31, 1.75	2.67***	2.32, 3.09
Shortness of breath when walking with others	1.62***	1.27, 2.06	2.82***	2.25, 3.53
Cardiovascular risk factors				
High total cholesterol (≥6.5 mmol/l)	1.53***	1.27, 1.84	1.75*	1.46, 2.10
Low HDL-cholesterol (≤0.9 mmol/l)	1.46*	1.07, 1.98	3.34***	2.54, 4.40
Hypertension‡	1.57***	1.21, 2.05	3.91***	3.10, 4.94
At least one risk factor	1.59***	1.37, 1.86	2.77***	2.38, 3.21
Diabetes				
Non-insulin dependent diabetes mellitus	0.84	0.34, 2.05	3.76***	1.94, 7.31
Low back pain				
Chronic low back pain (total ≥12 weeks/year)	1.26***	1.09, 1.47	1.41***	1.21, 1.64
Symptom of intervertebral disc hermiation	1.09	0.93, 1.27	1.41***	1.20, 1.65
'Poor' quality of life				
Difficulties in physical functioning				
Vigorous activities§	1.14	0.91, 1.43	1.77***	1.39, 2.26
Moderate activities§	1.18	0.90, 1.56	1.76***	1.35, 2.30
Lift/carry groceries§	1.08	0.84, 1.39	1.54***	1.21, 1.98
Walking several flights of stairs§	1.23	0.93, 1.63	2.00***	1.53, 2.62
Walking one flight of stairs§	1.19	0.78, 1.82	2.03***	1.39, 2.96
Bending, kneeling§	1.29*	1.00, 1.68	2.43***	1.89, 3.12
Walking more than a mile§	1.31	0.98, 1.76	1.84***	1.38, 2.45
Walking several blocks§	1.05	0.70, 1.59	1.91***	1.32, 2.75
Walking one block§	0.90	0.55, 1.48	1.54*	1.00, 2.38
Bathing or dressing§	0.91	0.47, 1.76	0.97	0.51, 1.84
'Poor' physical functioning#	1.17	0.79, 1.74	2.10***	1.48, 3.00

***P <0.001, **P <0.01, *P <0.05; †odds ratio with reference to waist circumference <94 cm (below Action Level 1); ‡systolic ≥160 or diastolic blood pressure ≥95 mmHg or medication for hypertension; §single items of physical functioning concept; #<66.7% standardised scores.

Table 6.2.5. Proportions of subjects whose daily life were affected due to low back pain in the past twelve months (n = 2467 men, 3448 women) in different categories of waist circumference Action Levels, adjusted for age, smoking, and education.

	Men			Women		
	Waist circumference (cm)			Waist circumference (cm)		
	<94	94-102	≥102	<80	80-88	≥88
Proportions (%)†	(56.6)	(24.6)	(18.8)	(48.8)	(25.1)	(26.1)
Daily business hindered	28.0	27.4	32.0	25.9	26.8	32.0**
Absence from work	23.8	25.8	25.3	19.4	21.4	25.0*
Medical consultation	38.6	43.6*	40.6	39.7	41.7	46.3**
Job redundancy	10.6	12.0	16.8**	7.4	8.6	11.8**
Job modification	8.2	7.4	10.8	7.2	6.6	6.2

Difference from waist <94 cm in men or <80 cm in women: ** P <0.01, * P <0.05; †proportions of subjects in each waist circumference category.

Table 6.2.6a. Odds ratios of symptoms of chronic diseases and poor subjective health in different categories of waist circumference Action Levels in men, adjusted for age and lifestyle factors (see **Appendix 6.2.1**).

	Waist circumference			
	≥94 (Action Level 1)		≥102 (Action Level 2)	
	OR†	95% CI	OR††	95% CI
Respiratory symptoms	P = 0.421‡		P = 0.180‡	
Wheezing when not having a cold	1.24*	1.02, 1.50	1.36**	1.09, 1.70
Woken up by shortness of breath	1.25	0.97, 1.61	1.18	0.89, 1.56
Coughing for more than 3 months	1.21	0.91, 1.39	1.06	0.82, 1.36
Bring up phlegm for more than 3 months	1.08	0.87, 1.35	1.08	0.83, 1.40
Shortness of breath when walking uphill/stairs	2.09***	1.79, 2.45	2.57***	2.18, 3.04
Shortness of breath when walking with others	1.92***	1.46, 2.54	2.33***	1.79, 3.05
Cardiovacular risk factors	P = 0.421‡		P = 0.180‡	
High total cholesterol	1.86***	1.59, 2.19	1.94***	1.64, 2.31
Low HDL-cholesterol	2.66***	2.31, 3.07	2.31***	1.97, 2.71
Hypertension	2.89***	2.37, 3.52	3.08***	2.56, 3.71
At least one risk factor	2.89***	2.56, 3.25	3.06***	2.65, 3.54
Diabetes	P = 0.421‡		P = 0.180‡	
Non-insulin dependent diabetes mellitus	3.10***	1.83, 5.24	3.08***	2.00, 4.72
Symptoms of low back pain	P = 0.421‡		P = 0.180‡	
Chronic low back pain (total ≥12 weeks/year)	1.16*	1.00, 1.35	1.10	0.93, 1.31
Symptom of intervertebral disc hermiation	1.17	1.00, 1.38	1.03	0.85, 1.24
'Poor' quality of life	P = 0.419‡		P = 0.185‡	
Difficulties in physical functioning				
Vigorous activities§	1.59***	1.29, 1.96	1.34*	1.04, 1.74
Moderate activities§	1.45***	1.08, 1.97	1.39	1.00, 1.94
Lifting carrying groceries§	1.32*	1.01, 1.73	1.36*	1.00, 1.84
Walking several flights of stairs§	1.92***	1.44, 2.55	2.20***	1.63, 2.98
Walking one flight of stairs§	1.29	0.84, 1.96	1.92**	1.25, 2.95
Bending, kneeling§	1.68***	1.33, 2.12	2.03***	1.56, 2.64
Walking more than a mile§	1.91***	1.44, 2.54	1.84***	1.35, 2.50
Walking several blocks§	2.05***	1.39, 3.01	2.12***	1.44, 3.13
Walking one block§	1.66*	1.06, 2.61	2.16***	1.37, 3.14
Bathing or dressing§	1.66	0.99, 2.78	2.02***	1.20, 3.39
'Poor' physical functioning¶	2.19***	1.48, 3.25	2.15***	1.46, 3.18

***P <0.001, **P <0.01, *P <0.05; odds ratio with reference to waist †below Action Level 1 (<94 cm) and ††below Action Level 2 (<102 cm); ‡P = proportion of subjects 'exposed' to the risk of large waist according to Action Levels; §single items of physical functioning concept; ¶standardised scores <66.7%.

Table 6.2.6b. Odds ratios of symptoms of chronic diseases and poor subjective health in different categories of waist circumference Action Levels in women , adjusted for age and lifestyle factors (see **Appendix 6.2.1**).

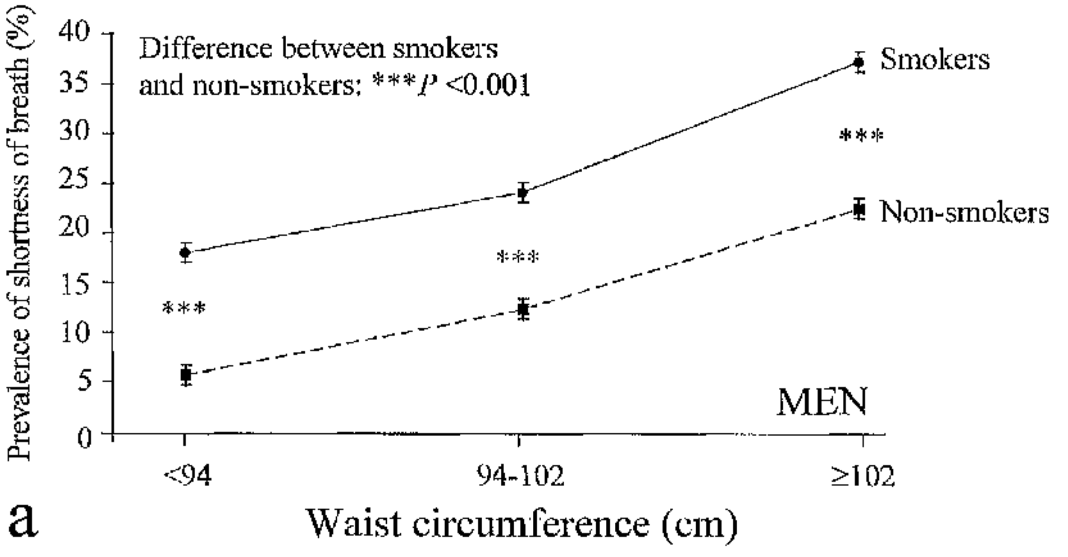
	Waist circumference Action Levels			
	≥80 (Action Level 1)		≥88 (Action Level 2)	
	OR†	95% CI	OR††	95% CI
Respiratory symptoms	P = 0.483‡		P = 0.239‡	
Wheezing when not having a cold	1.41***	1.17, 1.70	1.51***	1.24, 1.84
Woken up by shortness of breath	1.56***	1.26, 1.94	1.41**	1.13, 1.77
Coughing for more than 3 months	1.36**	1.12, 1.66	1.46***	1.18, 1.79
Bring up phlegm for more than 3 months	1.20***	0.95, 1.52	1.48**	1.15, 1.89
Shortness of breath when walking uphill/stairs	1.99***	1.76, 2.25	2.24***	1.97, 2.55
Shortness of breath when walking with others	2.17***	1.77, 2.66	2.28***	1.88, 2.76
Cardiovacular risk factors	P = 0.483‡		P = 0.239‡	
High total cholesterol	1.64***	1.39, 1.92	1.42***	1.21, 1.67
Low HDL-cholesterol	2.28***	1.78, 2.92	2.86***	2.25, 3.62
Hypertension	2.66***	2.14, 3.31	3.12***	2.60, 3.76
At least one risk factor	2.10***	1.85, 2.39	2.24***	1.97, 2.56
Diabetes	P = 0.483‡		P = 0.239‡	
Non-insulin dependent diabetes mellitus	2.34***	1.24, 4.43	4.07***	2.35, 7.04
Symptoms of low back pain	P = 0.483‡		P = 0.239‡	
Chronic low back pain (total ≥12 weeks/year)	1.33***	1.17, 1.51	1.27***	1.12, 1.45
Symptom of intervertebral disc herniation	1.23**	1.08, 1.41	1.36***	1.18, 1.57
'Poor' quality of life	P = 0.469‡		P = 0.238‡	
Difficulties in physical functioning				
Vigorous activities§	1.39***	1.15, 1.68	1.70***	1.35, 2.14
Moderate activities§	1.44**	1.15, 1.80	1.66***	1.31, 2.11
Lifting carrying groceries§	1.28*	1.04, 1.58	1.51***	1.21, 1.90
Walking several flights of stairs§	1.56***	1.24, 1.96	1.86	1.46, 2.37
Walking one flight of stairs§	1.61**	1.15, 2.27	1.89***	1.36, 2.64
Bending, kneeling§	1.77***	1.43, 2.19	2.20***	1.75, 2.76
Walking more than a mile§	1.53***	1.20, 1.95	1.66***	1.28, 2.16
Walking several blocks§	1.46*	1.06, 2.03	1.88***	1.35, 2.61
Walking one block§	1.23	0.83, 1.81	1.62*	1.10, 2.39
Bathing or dressing§	0.94	0.55, 1.62	1.01	0.56, 1.82
'Poor' physical functioning¶	1.56**	1.15, 2.16	1.97***	1.44, 2.70

***P <0.001, **P <0.01, *P <0.05; odds ratio with reference to waist †below Action Level 1 (<80 cm) and ††below Action Level 2 (<88 cm); ‡P = proportion of subjects 'exposed' to the risk of large waist according to Action Levels; §single items of physical functioning concept; ¶standardised scores <66.7%.

Table 6.2.6. Population attributable risks of symptoms due to large waist circumference in men.

	Population attributable risk (%)			
	Men		Women	
	≥94*	≥102**	≥80*	≥88**
Respiratory symptoms				
Wheezing when not having a cold	9.2	6.1	16.5	10.9
Woken up by SOB	9.5	3.1	21.3	8.9
Coughing for more than 3 months	8.1	1.1	14.8	9.9
Bring up phlegm for more than 3 months	3.3	1.42	8.8	10.3
SOB when walking uphill/stairs	31.5	22.0	32.4	22.9
SOB when walking with others	27.9	19.3	36.1	23.4
Cardiovacular risk factors				
High total cholesterol	26.6	14.5	23.6	9.1
Low HDL-cholesterol	41.1	19.1	38.2	30.8
Hypertension	44.3	27.3	44.5	33.6
At least one risk factor	44.3	27.1	34.7	22.9
Diabetes				
Non-insulin dependent diabetes mellitus	46.9	27.3	39.3	42.3
Symptoms of low back pain				
Chronic low back pain (total ≥12 wks/yr)	6.3	1.8	13.8	6.1
Symptom of intervertebral disc hermiation	6.7	0.5	10.0	7.9
'Poor' quality of life				
Difficulties in physical functioning†				
Vigorous activities†	19.8	5.9	15.5	14.3
Moderate activities†	15.9	6.7	17.1	13.6
Liftingcarrying groceries†	11.8	6.2	11.6	10.8
Walking several flights of stairs†	27.8	18.2	20.8	17.0
Walking one flight of stairs†	10.8	14.5	22.2	17.5
Bending, kneeling†	22.2	16.0	26.5	22.2
Walking more than a mile†	27.6	13.5	41.8	28.3
Walking several blocks†	30.6	17.2	17.8	17.3
Walking one block†	21.7	17.7	9.7	12.9
Bathing or dressing†	21.7	15.9	NA	0.2
'Poor' physical functioning‡	33.3	17.5	20.8	18.8

*NA, not applicable as odds ratio <1; reference group with waist circumference *below Action Level 1 (<94 cm in men, <80 cm in women) and **below Action Level 2 (<102 cm in men, <88 cm in women); †single items of physical functioning concept; ‡<66.7% standardised scores.



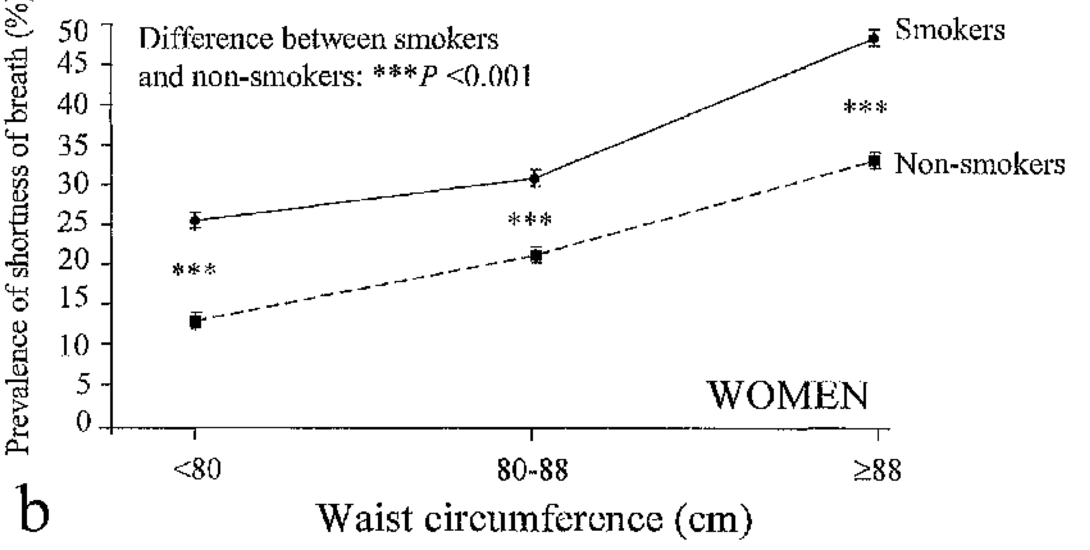


Figure 6.2.1. Age adjusted prevalence of shortness of breath when walking uphill or upstairs in smokers and non-smokers in different categories of waist circumference based on Action Levels (Lean *et al*, 1995) in men (a) and in women (b).

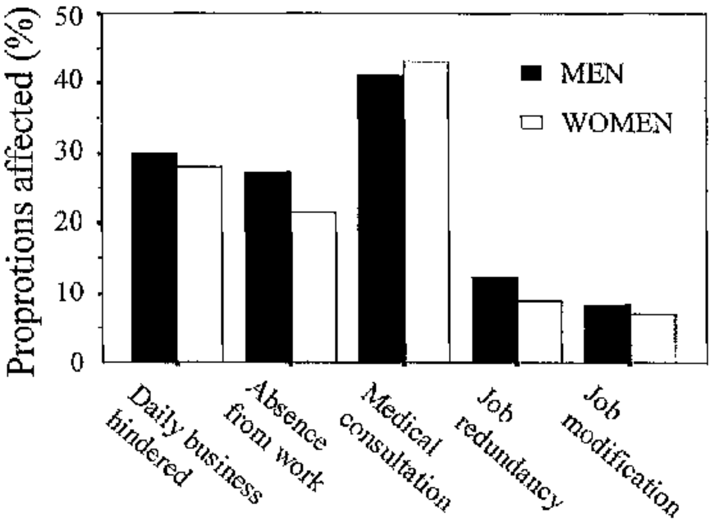


Figure 6.2.2. The proportions of subjects whose daily activities are affected by low back pain in the past twelve months.

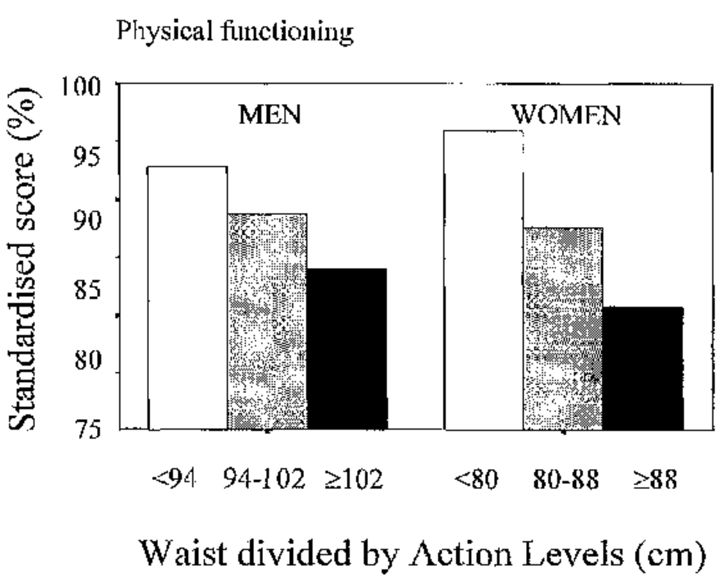


Figure 6.2.3. Standardised scores of physical functioning concept in men and women in different categories of waist circumference based on Action Levels (Lean *et al*, 1995).

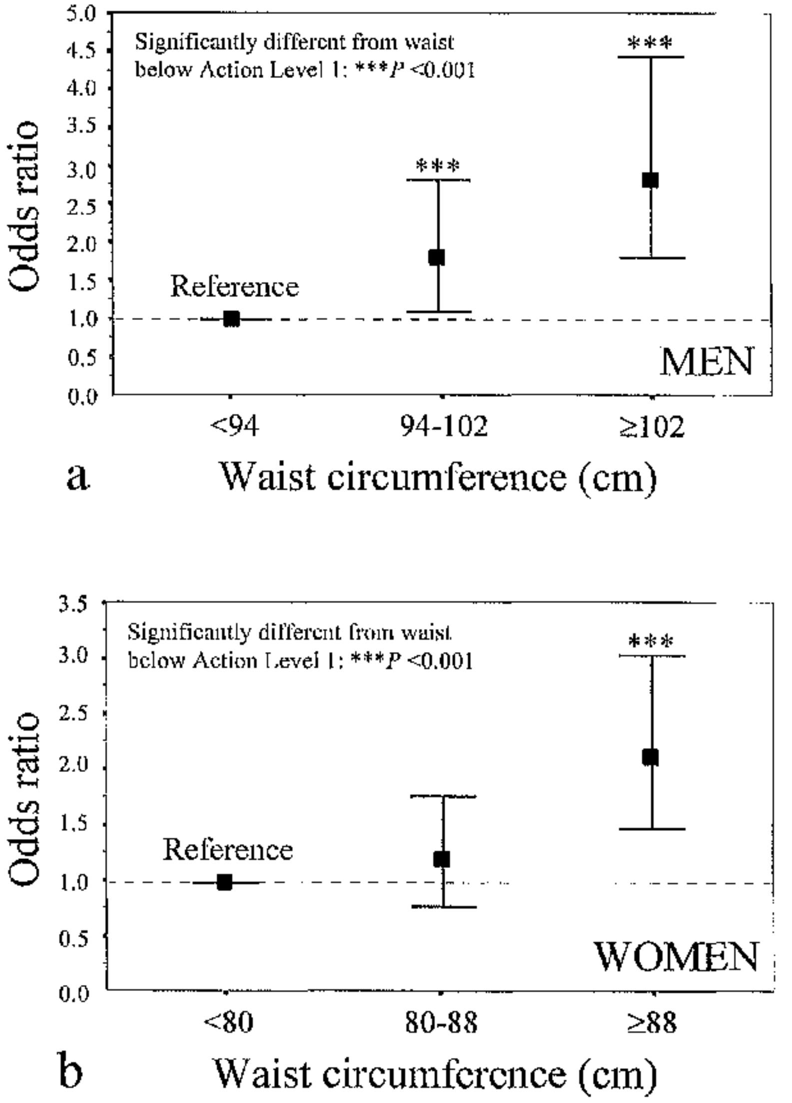


Figure 6.2.4. Odds ratios for poor physical functioning (standardised scores <66.7%) in men (a) and women (b) in different categories of waist circumference based on Action Levels (Lean *et al*, 1995). Odds ratios adjusted for age, lifestyle and demographic factors.

Appendix 6.2.1. Age, lifestyle and demographic factors as possible confounders considered in analysis of the associations of symptoms of chronic disease and impaired quality of life with waist circumference.

	Reference group	Dummy variables		
		1	2	3
Age (years)[a,b,c,d,e]	20-29	30-39	40-49	50-59
Smoking[a,b,c,d,e]	Non-smokers	Ex-smokers	Current smokers	
Alcohol consumption (glasses/day)[a,b,c,e]	Occasional (<1)	None (0)	Moderate (1 to <3)	Heavy (≥3)
Physical activity [a,b,c,e]	Active (do sport)	Inactive (do no sport)		
Educational level [a,b,c,d,e]	Level 3 (higher vocational or university)	Level 2 (vocational or higher secondary)	Level 1 (lower than secondary)	
Marital status[e]	Single	Married or cohabiting	Divorced or widowed	
Employment[e]	Currently employed	Unemployed	Housewives	Retired early
Household composition[e]	Living with someone	Living with no one		
Intimate contact†[e]	No one	1-2	3-5	≥6
Parity (live births)[e]	None	1-2	≥3	

Factors corrected for in logistic regression analysis: [a]respriatory symptoms, [b]cardiovascular risk factors, [c]diabetes, [d]low back pain, and [e]quality of life; †discussing personal matters with other people.

CHAPTER SEVEN

WEIGHT MANAGEMENT: RELATING TO CHANGES IN BODY MORPHOLOGY AND CARDIOVASCULAR RISK FACTORS

CONTENTS OF CHAPTER SEVEN **PAGES**

— 7.1 —

WAIST REDUCTION AND CARDIOVASCULAR BENEFITS DURING WEIGHT MANAGEMENT IN WOMEN

This section has been peer reviewed and has been published as

Han TS, Richmond PR, Avenell A, Lean MEJ. Waist circumference reduction and cardiovascular benefits during weight management in women. *International Journal of Obesity* 1997; **21**:127-34.

Collaboration with Aberdeen Weight Loss study

ABSTRACT

Objective: To examine the relationship between waist circumference and cardiovascular risk factors during weight loss, and to consider possible waist reduction targets for weight management.

Design: Single strand six month weight loss study on food based diets in 110 women aged 18-68 years, and body mass index ≥25 kg/m^2 set at an outpatient clinic.

Main outcome measures: Waist circumference, weight, body mass index (BMI), total plasma cholesterol, low (LDL) and high density lipoprotein (HDL) cholesterol, triglyceride, and blood pressure.

Results: Anthropometric and metabolic measurements improved with mean weight loss of 4.9 (SE ±0.4) kg at three months and 6.2 (SE ±0.4) kg at six months. Weight loss closely related to waist reduction (*%Weight loss = 0.85 × Waist reduction (cm) - 2.09*; $r = 0.79$). The proportion of subjects with waist circumference below 80 cm (Action Level 1) or above 88 cm (Action Level 2) were 9% and 60% at baseline, 29% and 38% at three months and 36% and 33% at six months. Waist reduction (adjusted for age, smoking, alcohol consumption, diet treatment and baseline dependent and independent variables) correlated significantly with falls in total cholesterol ($r = 0.31$; $P < 0.01$), LDL cholesterol ($r = 0.35$; $P < 0.01$) and diastolic blood pressure ($r = 0.32$; $P < 0.01$), but not significantly with HDL cholesterol, triglyceride or systolic blood pressure. BMI showed similar correlations, whereas waist to hip ratio changes were not associated with changes in any cardiovascular risk factors. Amongst those whose waist fell by ≥5 cm, 45 at three months and 43 at six months, there were ≥10% improvements in at least one risk factor for 71% and 84% respectively. Amongst those whose waist fell by 5 to 10 cm, 40 women at three months and 30 at six months, at least one risk factor improved in 70% and in 83% respectively.

Conclusions: Waist reduction of 5 to 10 cm in Caucasian women, across a range of baseline BMI 25-50 kg/m^2 or waist circumference 72-133 cm, may be used as guideline to encourage overweight women to achieve a realistic target with a high probability of health benefits.

INTRODUCTION

Obesity, a preventable disease with a huge burden of symptoms and secondary health problems, is rising in prevalence in Britain (Gregory *et al*, 1990; Bennett *et al*, 1995). Treatment of obesity is difficult, many people become disillusioned with their apparently slow progress and fluctuations in body weight during slimming often in the context of unreasonable targets. Maintaining modest weight loss may lead to more sustained health benefits and thus a greater overall health improvement than attempting the large weight loss required to achieve ideal body weight (Lean *et al*, 1990; Goldstein *et al*, 1992; Dattilo *et al*, 1992; Atkinson *et al*, 1993; Williamson *et al*, 1995; Wadden *et al*, 1996).

Waist circumference reduction is a rewarding consequence of slimming and has been suggested as a better motivator than weight change (Egger *et al*, 1995). We have recently proposed the use of waist circumference for health promotion as a simple method for detecting overweight (body mass index) and central fat distribution (waist to hip ratio) (**Chapter 4.1**; Lean *et al*, 1995) , and for identifying people with cardiovascular risk factors (**Chapter 5.2**; Han *et al*, 1995c; **Chapter 4.2**; Han *et al*, 1996c). People with waist circumference between Action Level 1 and Action Level 2, (the 'Alert Zone', ≥94-102 cm in men, ≥80-88 cm in women) have increased cardiovascular risks, and above Action Level 2 (the 'Action Zone', ≥102 cm in men, ≥88 cm in women), the cardiovascular risks are approximately tripled (**Chapter 5.2**; Han *et al*, 1995c).

The present study examined the relationships between anthropometric measurements and cardiovascular risk factors during six months of weight loss, and considered possible targets for weight management based on changes in waist circumference.

METHODS

Subjects and dietary advice

Women aged 18 to 68 years, body mass index ≥25 kg/m^2, free from active disease or drugs known to affect body weight, were recruited for a study of six month weight management. Two 1200 kcal/day diets were randomly allocated, after pilot studies to determine acceptability, containing 58% energy (n = 57) or 35% energy from carbohydrate (n = 53). Dietary advice, given by the same dietitian (PR), employed food exchanges supported by appropriate recipes.

Anthropometry

Body weight was measured to the nearest 0.1 kg in light clothes and height to the nearest 0.1 cm. Body mass index was calculated as weight (kg) divided by height squared (m^2). Waist circumference midway between the lowest rib margin and the iliac crest and hip circumference level with the greater trochanters were measured to the nearest mm (**Chapter 3.1**; Lean *et al*, 1996; World Health Organisation, 1989). Body fat (as % body weight) was calculated from waist circumference (**Chapter 3.1**; Lean *et al*, 1996), Skinfold thicknesses were measured (Durnin and Womersley, 1974) but gave identical results for body fat, as calculated from waist, so data are not presented.

Risk factor measurements

Total plasma cholesterol, high density lipoprotein cholesterol, and triglyceride were measured using standard laboratory methods, and low density lipoprotein cholesterol was calculated (Fiedewald *et al*, 1972). Systolic and diastolic blood pressures (first and fourth Korotkoff sounds) were recorded with subjects lying and rested five minutes. Information on alcohol consumption (units/week) and smoking (cigarettes per day) were assessed by questionnaire.

Statistical methods

Subjects were categorised into three groups according to the previously defined cut-offs of waist circumference for women: below Action Level 1 (<80 cm), between Action

Level 1 and Action Level 2 (≥80-88 cm), and above Action Level 2 (≥88 cm) (**Chapter 4.1**; Lean *et al*, 1995). Improvements in risk factors were defined as ≥10%. Cross tabulation was used to determine the proportions of subjects who improved risk factors through waist reduction, and to test (Chi square) the differences in improvements according to waist circumference.

RESULTS

Seventeen percent (n = 19) of recruits dropped out before three months and 25.5% (n = 28) by six months. The dropouts were 13 years younger (P <0.001) than those who continued. There were no significant differences in body mass index (P = 0.24 at three months and P = 0.38 at six months) or in waist circumference (P = 0.18 at three months and P = 0.25 at six months) between the two diet groups (high carbohydrate or low carbohydrate). The numbers and ages of dropouts were not significantly different between the two diet groups throughout the study. Baseline measurements and changes in anthropometry and cardiovascular risk factors were not significantly different between the two diet groups at three months (**Table 7.1.1**) or at six months (**Table 7.1.2**), so all 110 women were analysed together to examine the relationships between changes in anthropometry and changes in cardiovascular risk factors. Characteristics of all 110 women are shown in **Table 7.1.3**.

Anthropometric measurements followed similar patterns with 60-70% of total decreases within the first three months, with associated improvements in blood lipid. At six months, total cholesterol and triglyceride remained significantly below the baseline values, but high density lipoprotein cholesterol returned to the baseline value. Low density lipoprotein cholesterol and blood pressures did not change significantly (**Table 7.1.4**).

At three months of weight management, the proportion of women with waist circumferences in the 'Action Zone' (≥88 cm) was reduced from 59.6 to 38.2% of the sample, and those with waist below Action Level 1 (<80 cm) increased from 9.2 to 29.2%. By six months, women with baseline waist ≥88 cm decreased to 33.3%, whilst those with waist <80 cm increased to 35.8%. The proportion of women with waist ≥80-88 cm remained between 29-31% throughout the study (**Figure 7.1.1**). Amongst those whose baseline waist was in the 'Action Zone', 26.0% at three months and 29.8% at six months moved into the 'Alert Zone', and 6% at three months and 13% at six months fell to below Action Level 1. Amongst those whose baseline waist was in the 'Alert Zone', 56.7% at three months and 56.0% at six months dropped to below Action Level 1 of waist circumference. The relationship between changes in weight and waist (**Table 7.1.5**) or changes in cardiovascular risk factors (**Table 7.1.6**) was not significantly influenced by baseline waist circumference.

At three months, decreases in total cholesterol, low density lipoprotein cholesterol and triglyceride correlated significantly with decreases in body weight and body mass index. At six months, decreases in total cholesterol, low density lipoprotein cholesterol, and diastolic blood pressure correlated with body weight, body mass index and waist circumference (**Table 7.1.7**). Changes in waist to hip ratio did not correlate with changes in any of the cardiovascular risk factors throughout the study.

Changes in waist circumference related closely to changes in body weight (**Figure 7.1.2**). Regression analysis showed reduction in waist circumference correlated more strongly with percentage change in body weight ($r = 0.70$ at three months and $r = 0.75$ at six months) than with changes in the absolute amount of body weight ($r = 0.63$ at three months and $r = 0.68$ at six months). Reduction of 5 to 10 cm of waist circumference predicted 6.3 to 10.6% of weight loss (**Equation 1**). Weight loss of 5 to 10% predicted 4.7 to 8.0 cm of waist reduction (**Equation 2**).

Amongst women who improved risk factors by ≥10%, plasma triglyceride reduction accounted for 54% at three months and 56% at six months. Other risk factors improved by ≥10% for 17-27% of women at three months and 27-30% at six months, and about three quarters of all subjects improved at least one of the five risk factors considered by ≥10% (**Table 7.1.8**). In general, amongst women with waist reductions of 5-10 cm, 70% improved at least one risk factor by ≥10% at three months and 83% at six months (**Table 7.1.9**). The improvements with waist reduction were similar for women with different categories of waist circumference at baseline (data not shown).

DISCUSSION

There are currently no universally accepted standards or criteria defining successful weight management. From **Table 7.1.7** it can be seen that weight, body mass index and waist circumference related to major cardiovascular risk reduction during slimming. The results are similar to those studies of weight loss. In our free living subjects, energy balance was restored at about 3 months in most subjects. The changes in certain measurements reflect the independent effects of acute energy reduction and of weight loss, for example the biphasic changes in plasma high density lipoprotein cholesterol (Dattilo *et al*, 1992). Recognising the ease of measurement and motivational value, we have focused on waist reduction using cut-offs defined in an earlier study of body mass index and waist to hip ratio (**Chapter 4.1**; Lean *et al*, 1995). The 'Gutbuster' programme in Australia using waist circumference to encourage weight management in men, with a target of 1% of waist reduction a week, showed 75% of men maintained more than 5% of waist reduction at 2 years (Egger *et al*, 1995).

Risk factor improvements of 10% probably have major long term benefits (Law *et al*, 1994; Verschuren, 1995). Amongst women who achieved waist reduction from 5 to 10 cm in the present study, over 80% had improved at least one risk factor by ≥10%, and since weight loss was almost complete by three months, this improvement is likely to reflect loss of weight, not acute negative energy balance. Risk factor improvements were no greater in those who lost ≥7.5 or ≥10 cm of waist (**Table 7.1.9**), and did not differ with baseline waist (**Table 7.1.6**). Few comparable data exist, by Andersen *et al* (1995) found that a 5.6% reduction of body weight in overweight women improved total cholesterol by 21% and triglyceride by 19%, and these improvements in cardiovascular risk factors were as great as in those who had achieved 11% weight loss. The same study showed similar pattern of weight loss and waist reduction in 66 overweight women, treated with a diet of 925 kcal/day for 3 months followed by 1500 kcal/day for 15 months. A 16.4% weight loss at six months was accompanied by 13 cm of waist reduction, falls in total cholesterol and triglyceride, and high density lipoprotein cholesterol returned to baseline value after a temporary decrease during the phase of negative energy balance (at two months) (Anderson *et al*, 1995). Colman *et al* (1995) found 9 kg weight loss reduced waist circumference by 7 cm in men, with waist circumference being the strongest predictor of improved glucose tolerance.

Using Action Level derived from large population study (**Chapter 4.1**; Lean *et al*, 1995; **Chapter 5.2**; Han *et al*, 1995c), it is proposed that those with waist circumference below Action Level 1, who have relatively little of the intra-abdominal fat (Pouliot *et al*, 1994), do not need to lose weight but should be aware of potential health risks when their waist approaches this level. In the 'Alert Zone' (≥94-102 cm in men, ≥80-88 cm in women), subjects should avoid weight gain, and some self-managed weight loss by lifestyle modification such as increasing physical activity level (Blair, 1993; Kempen *et al*, 1995; Racette *et al*, 1995; Wood, 1993). Patients in this 'Alert Zone' of waist range with problems like non-insulin dependent diabetes mellitus, hypertension, or angina would benefit from more active weight loss (Schuler *et al*, 1992; Yamanouchi *et al*, 1995). Above this range, termed the 'Action Zone' (≥102 cm in men, and ≥88 cm in women), professional help should be sought to achieve sustained weight loss and for risk factor screening.

CONCLUSIONS

The present study extends the value of waist measurement into management. In conclusion, reduction in waist circumference, weight or body mass index produces beneficial effects on certain cardiovascular risk factors, whereas waist to hip ratio reduction is less powerful predictor of risk factor improvements. Modest weight loss associated with 5 to 10 cm of waist reduction appears a reasonable initial target for weight management in overweight Caucasian women irrespective of body mass index or baseline waist circumference, and will produce beneficial effects on cardiovascular risk factors.

Table 7.1.1. Changes from baseline values in anthropometric and metabolic measurements of women who continued on the study until three months on a high carbohydrate (58% of energy) or low carbohydrate (35% of energy).

	High carbohydrate diet			Low carbohydrate diet			
	n	Mean†	95% CI	*n*	Mean †	95% CI	*P*‡
Weight (kg)	48	-4.3***	-5.3, -3.3	43	-5.6***	-6.8, -4.3	0.109
BMI (kg/m^2)	48	-1.7***	-2.1, -1.3	43	-2.2***	-2.6, -1.7	0.104
Waist (cm)	48	-4.2***	-5.4, -3.0	41	-5.0***	-6.3, -3.8	0.331
Hips (cm)	48	-3.5***	-4.5, -2.5	41	-4.0***	-5.1, -3.0	0.503
Waist to hip ratio	48	-0.013**	-0.022, -0.004	41	-0.017**	-0.028, -0.006	0.512
Percent body fat§	48	-1.8***	-2.4, -1.3	41	-2.2***	-2.8, -1.7	0.331
Cholesterol¶	46	-0.33**	-0.55, -0.10	38	-0.21^{ns}	-0.43, 0.02	0.446
LDL¶	43	-0.23*	-0.43, -0.02	36	-0.01^{ns}	-0.20, 0.19	0.114
HDL¶	43	-0.05*	-0.10, -0.03	36	-0.03^{ns}	-0.10, 0.04	0.579
Triglyceride¶	44	-0.15^{ns}	-0.32, 0.03	36	-0.28**	-0.48, -0.08	0.323
SBP (mmHg)	40	-2.0^{ns}	-7.2, 3.2	38	-1.9^{ns}	-7.8, 4.1	0.973
DBP (mmHg)	40	-1.3^{ns}	-4.7, 2.2	38	-2.1^{ns}	-6.4, 2.1	0.745

†Paired *t*-test compared to baseline: ****P* <0.001; ***P* <0.01; **P* <0.05; ns, not significant; ‡independent *t*-test for differences between groups of the changes in anthropometry and cardiovascular risk factors; §percent body fat (percent of body weight) estimated from waist circumference, adjusted for age (Lean *et al*, 1996); ¶unit = of measurement = mmol/l; BMI = body mass index; LDL = low density lipoprotein cholesterol, HDL = high density lipoprotein cholesterol; SBP = systolic blood pressure; DBP = diastolic blood pressure.

Table 7.1.2. Changes from baseline values in anthropometric and metabolic measurements of women who continued on the study until six months (completers) on a high carbohydrate (58% of energy) or low carbohydrate (35% of energy).

	High carbohydrate diet			Low carbohydrate diet			
	n	Mean†	95% CI	*n*	Mean†	95% CI	*P*‡
Weight (kg)	42	-5.6***	-7.1, -4.1	40	-6.8***	-8.4, -5.2	0.283
BMI (kg/m^2)	42	-2.2***	-2.7, -1.6	40	-2.6***	-3.3, -2.0	0.257
Waist (cm)	41	-5.7***	-7.2, -4.2	40	-6.5***	-8.1, -4.9	0.470
Hips (cm)	41	-5.2***	-6.6, -3.8	40	-5.7***	-7.0, -4.4	0.577
Waist to hip ratio	41	-0.015**	-0.026, -0.004	40	-0.019**	-0.030, -0.007	0.624
Percent body fat§	41	-2.5***	-3.2, -1.9	40	-2.9***	-3.5, -2.2	0.470
Cholesterol¶	40	-0.34**	-0.56, -0.13	37	-0.12^{ns}	-0.42, 0.17	0.233
LDL¶	37	-0.17^{ns}	-0.36, 0.02	34	-0.03^{ns}	-0.29, 0.24	0.368
HDL¶	37	-0.02^{ns}	-0.08, 0.05	34	+0.05^{ns}	-0.03, 0.14	0.180
Triglyceride¶	39	-0.27**	-0.45, -0.10	34	-0.25*	-0.44, -0.06	0.828
SBP (mmHg)	38	-1.1^{ns}	-6.6, 4.4	36	-0.3^{ns}	-6.1, 5.6	0.836
DBP (mmHg)	38	-2.7^{ns}	-6.4, 1.1	36	-2.3^{ns}	-6.1, 1.5	0.894

†Paired *t*-test compared to baseline: ****P* <0.001; ***P* <0.01; **P* <0.05; ns, not significant; ‡Independent *t*-test for differences between groups of the changes in anthropometry and cardiovascular risk factors; §Percent body fat (percent of body weight) estimated from waist circumference, adjusted for age (Lean *et al*, 1996); ¶unit of measurement = mmol/l; BMI = body mass index; LDL = low density lipoprotein cholesterol, HDL = high density lipoprotein cholesterol; SBP = systolic blood pressure; DBP = diastolic blood pressure.

Table 7.1.3. Baseline physical and metabolic characteristics of 110 women.

	Mean	SD	Range
Age (years)	50.6	13.7	18.0-68.0
Weight (kg)	84.3	15.8	62.9-152.7
Height (m)	1.61	0.06	1.46-1.77
Body mass index (kg/m^2)	32.6	5.3	24.5-49.8
Waist circumference (cm)	92.5	11.7	72.0-133.0
Hip circumference (cm)	113.6	11.7	97.5-152.5
Waist to hip ratio	0.814	0.053	0.706-0.948
Body fat (% of body weight)*	42.4	5.3	30.1-55.7
Cholesterol (mmol/l)	6.64	1.35	4.10-11.40
Low density lipoprotein (mmol/l)	4.47	1.05	2.60-7.00
High density lipoprotein (mmol/l)	1.46	0.37	0.80-2.60
Triglyceride (mmol/l)	1.48	0.85	0.40-5.50
Systolic blood pressure (mmHg)	136.2	22.5	92.0-194.0
Diastolic blood pressure (mmHg)	85.1	12.1	60.0-120.0
Mean arterial blood pressure (mmHg)	102.1	14.8	72.0-141.3

All variables were not significantly different between the two diet treatment groups. *Note*: Recalculations of body mass index found two subjects whose baseline values were below 25 kg/m^2 (24.5 and 24.9); *body fat calculated from waist circumference (Lean *et al*, 1996).

Table 7.1.4. Changes in anthropometric and metabolic measurements of women who had 1200 kcal/day diets from baseline to six months.

	Baseline to 3 months			Baseline to 6 months		
	n	Mean†	95% CI	*n*	Mean†	95% CI
Weight (kg)	91	-4.9***	-5.7, -4.1	82	-6.2***	-7.3, -5.1
BMI (kg/m^2)	91	-1.9***	-2.2, -1.6	82	-2.4***	-2.8, -2.0
Waist (cm)	89	-4.6***	-5.4, -3.7	81	-6.1***	-7.2, -5.0
Hips (cm)	89	-3.8***	-4.5, -3.0	81	-5.4***	-6.4, -4.5
Waist to hip ratio	89	-0.015**	-0.022, -0.008	81	-0.017**	-0.024, -0.009
Percent body fat‡	89	-2.0***	-2.4, -1.6	81	-2.7***	-3.1, -2.2
Cholesterol§	84	-0.27**	-0.43, -0.11	77	-0.24*	-0.42, -0.06
LDL§	79	-0.13	-0.27, 0.01	71	-0.10	-0.26, 0.05
HDL§	79	-0.04*	-0.08, -0.00	71	0.02	-0.03, 0.07
Triglyceride§	80	-0.21**	-0.34, -0.07	73	-0.26***	-0.39, -0.14
SBP (mmHg)	78	-1.9	-5.8, 1.9	74	-0.7	-4.6, 3.3
DBP (mmHg)	78	-1.7	-4.3, 1.0	74	-2.5	-5.1, 0.1
MAP (mmHg)	78	-1.8	-7.4, 1.6	74	-3.5	-7.9, 0.9

†Paired t-test: **P* <0.001; ***P* <0.01; **P* <0.05; ‡body fat (percentage of body weight) fat calculated from waist circumference (Lean *et al*, 1996); §unit of measurement = mmol/l; LDL = low density lipoprotein cholesterol, HDL = high density lipoprotein cholesterol; SBP = systolic blood pressure; DBP = diastolic blood pressure; MAP = mean arterial blood pressure.

Table 7.1.5. Changes in waist circumference and body weight in women classified into groups according to their Action Levels of waist circumference at baseline.

Baseline waist (cm)*		Baseline to 3 months				Baseline to 6 months			
	n	Mean	95%CI	*F*†	*P*	Mean	95%CI	*F*†	*P*
				Waist reduction (cm)					
<80	11	-3.2	-4.9, -1.5			-5.1	-7.7, -2.4		
80-88	34	-4.8	-6.1, -3.5	0.61	0.55	-6.1	-8.9, -5.4	0.26	0.78
≥88	65	-4.7	-5.9, -3.5			-6.3	-8.2, -4.9		
				Waist reduction (%)					
<80	11	-4.1	-6.3, -1.8			-6.5	-9.9, -3.1		
80-88	34	-5.7	-7.3, -4.2	0.61	0.55	-7.2	-8.9, -5.4	0.14	0.87
≥88	65	-4.8	-6.1, -3.5			-6.5	-8.2, -4.9		
				Weight loss (kg)					
<80	11	-4.1	-5.8, -2.4			-5.3	-7.6, -2.9		
80-88	34	-4.7	-5.7, -3.6	0.42	0.66	-5.9	-7.4, -4.5	0.30	0.74
≥88	65	-5.2	-6.4, -4.0			-6.5	-8.2, -4.9		
				Weight loss (%)					
<80	11	-6.1	-8.8, -3.4			-7.8	-11.5, -4.1		
80-88	34	-6.2	-7.6, -4.8	0.12	0.89	-7.7	-9.5, -5.9	0.14	0.87
≥88	65	-5.7	-7.3, -4.2			-7.1	-8.8, -5.4		

*Subject groups classified according to baseline waist circumference Action Levels (Action Level 1 = 80 cm, Action Level 2 = 88 cm (Lean *et al*, 1995)); †analysis of variance to determine whether losses in anthropometry were different in women whose baseline waist circumferences were in different groups according to Action Levels.

Table 7.1.6. Changes in cardiovascular risk factors in women classified into groups according to their Action Levels of waist circumference at baseline.

Baseline waist (cm)*		Baseline to 3 months				Baseline to 6 months			
	n	Mean	95%CI	*F*†	*P*	Mean	95%CI	*F*†	*P*
				Total cholesterol					
<80	11	-0.33	-1.07, 0.41			-0.26	-0.73, 0.22		
80-88	34	-0.21	-0.45, 0.03	0.15	0.86	-0.30	-0.58, -0.03	0.14	0.87
≥88	65	-0.30	-0.52, -0.07			-0.20	-0.47, 0.07		
				Low density lipoprotein cholesterol					
<80	11	-0.14	-1.01, 0.73			-0.21	-0.72, 0.29		
80-88	34	-0.09	-0.27, 0.09	0.07	0.93	-0.16	-0.39, 0.06	0.35	0.71
≥88	65	-0.15	-0.34, 0.05			-0.05	-0.28, 0.19		
				High density lipoprotein cholesterol					
<80	11	-0.04	-0.17, 0.10			-0.02	-0.21, 0.16		
80-88	34	-0.03	-0.10, 0.04	0.14	0.87	0.00	-0.09, 0.08	0.43	0.65
≥88	65	-0.05	-0.11, 0.00			0.04	-0.03, 0.11		
				Triglyceride					
<80	11	-0.20	-0.45, 0.05			-0.20	-0.40, 0.00		
80-88	34	-0.08	-0.26, 0.10	0.96	0.39	-0.23	-0.36, -0.09	0.17	0.84
≥88	65	-0.28	-049, -0.07			-0.29	-0.50. -0.09		
				Systolic blood pressure					
<80	11	-4..3	-15.6, 7.0			1.9	-9.1, 12.9		
80-88	34	-2.0	-9.2, 5.1	0.11	0.90	-4.2	-11.7, 3.2	0.84	0.44
≥88	65	-1.4	-6.8, 4.0			1.0	-4.4, 6.4		
				Diastolic blood pressure					
<80	11	-7.8	-17.6, 2.1			-2.9	-11.0, 5.2		
80-88	34	-3.1	-7.1, 0.9	2.17	0.12	-5.1	-9.2, -0.9	1.14	0.32
≥88	65	0.5	-3.3, 4.3			-0.8	-4.6, 3.0		
				Mean arterial blood pressure					
<80	11	-6.6	-16.2, 2.9			-1.3	-9.2, 6.6		
80-88	34	-2.7	-7.3, 1.8	1.14	0.33	-4.8	-9.6, 0.5	1.18	0.31
≥88	65	-0.2	-4.1, 3.8			-0.2	-4.1, 3.7		

*Subject groups classified according to baseline waist circumference Action Levels (Action Level 1 = 80 cm, Action Level 2 = 88 cm (Lean *et al*, 1995)); †analysis of variance to determine whether losses in cardiovascular risk factors were different in women whose baseline waist circumferences were in different groups according to Action Levels.

Table 7.1.7. Correlation coefficients between changes in anthropometric measurements and changes in risk factors adjusted for age, alcohol consumption, cigarette smoking, diet treatments and baseline dependent and independent variables of each corresponding pair of correlate.

	Weight	Body mass index	Waist†	Waist to hip ratio
		Baseline to three months		
Total cholesterol	0.365**	0.372**	0.219	-0.039
Low density lipoprotein	0.256**	0.271*	0.166	-0.073
High density lipoprotein	0.125	0.129	0.058	-0.077
Triglyceride	0.372**	0.349**	0.230*	0.126
Systolic blood pressure	-0.083	-0.081	-0.067	0.080
Diastolic blood pressure	-0.075	-0.063	-0.039	0.159
Mean blood pressure	-0.076	-0.068	-0.049	0.139
		Baseline to six months		
Total cholesterol	0.336**	0.339**	0.311**	0.183
Low density lipoprotein	0.333**	0.333**	0.347**	0.177
High density lipoprotein	0.029	0.025	0.011	0.042
Triglyceride	0.248*	0.251*	0.199	0.201
Systolic blood pressure	0.092	0.081	0.112	0.123
Diastolic blood pressure	0.287*	0.284*	0.319**	0.025
Mean blood pressure	0.228	0.220	0.259*	0.139

Significance levels: $^{**}P$ <0.01; $^{*}P$ <0.05; †body fat (% of body weight) calculated from waist circumference equation (Lean *et al*, 1996) gave identical correlation coefficients.

Table 7.1.8. The percentage of women whose waist reduced by different amounts, and those who improved cardiovascular risk factors by ≥10%, during six months of weight management.

	Improvement criterion	At 3 months $n = 89$* %‡	At 6 months $n = 81$* %‡
Waist circumference	↓ <5.0 cm	49.4	46.9
Waist circumference	↓ ≥5.0 cm	50.6	53.1
Waist circumference	↓ ≥7.5 cm	18.0	39.5
Waist circumference	↓ >10 cm	5.6	16.0
Waist circumference	↓ 5-10 cm	44.9	37.0
Total cholesterol	↓ ≥10%	27.4	28.6
Low density lipoprotein	↓ ≥10%	26.6	29.6
High density lipoprotein	↑ ≥10%	16.5	26.8
Triglyceride	↓ ≥10%	53.8	56.2
Mean blood pressure	↓ ≥10%	23.1	21.6
At least one risk factor	≥10%	73.5	80.0

*The number of subjects who completed the weight management programme; †percentage of subjects whose waist were reduced by different amounts, and those who improved cardiovascular risk factors by ≥10%.

Table 7.1.9. The numbers of women who underwent waist reduction of different amounts and who improved specific cardiovascular risk factors by ≥10 %, during six months of weight management.

	<5 cm (n = 44*) %†	≥5 cm (n = 45)* %†	≥7.5 cm (n = 16)* %†	≥10 cm (n = 5)* %†	5-10 cm (n = 40)* %†
			Three months		
Total cholesterol	17.1	37.2	37.5	50.0	34.2
Low density lipoprotein	15.0	38.5	33.3	33.3	38.2
High density lipoprotein	17.5	15.4	13.3	16.7	14.7
Triglyceride	53.7	53.8	73.3	83.3	50.0
Mean blood pressure	20.5	25.6	33.3	33.3	23.5
At least 1 risk factor	63.6	71.1	87.5	80.0	70.0
			Six months		
	(n = 38)*	(n = 43)*	(n = 32)*	(n = 13)*	(n = 30)*
Total cholesterol	19.4	36.6	43.8	42.9	32.1
Low density lipoprotein	12.5	43.6	54.8	42.9	42.3
High density lipoprotein	31.4	28.2	25.8	35.7	23.1
Triglyceride	55.9	56.4	61.3	64.3	53.8
Mean blood pressure	11.4	30.8	27.6	16.7	35.7
At least 1 risk factor	65.8	83.7	87.5	84.6	83.3

*The number of subjects whose waist was reduced by <5, ≥5, ≥7.5, ≥10, or 5-10 cm; †the percentage of subjects amongst those who improved risk factors by ≥10% through different amounts of waist reduction; improvement of at least one risk factor in those who lost 5-10 cm did not differ from that in those who lost ≥10 cm at 3 months (χ^2 = 0.22, P = 0.64) and at six months (χ^2 = 0.01, P = 0.92).

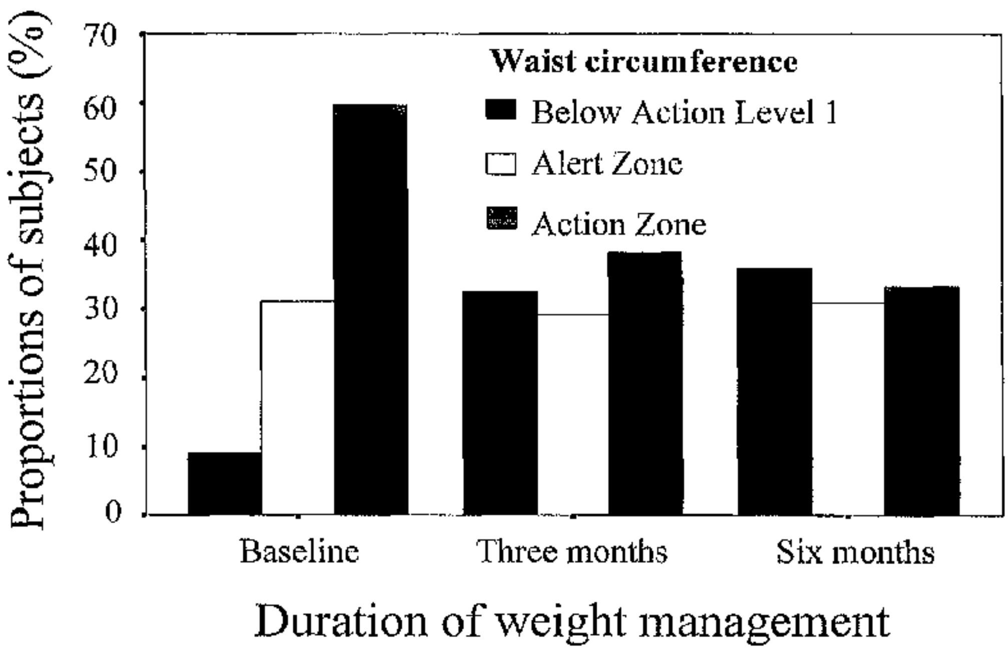


Figure 7.1.1. Distribution of waist circumference at baseline, three months and six months of weight management in women. Waist circumference: Action Level I = 80 cm, Alert Zone = 80-88 cm, and Action Zone ≥88 cm.

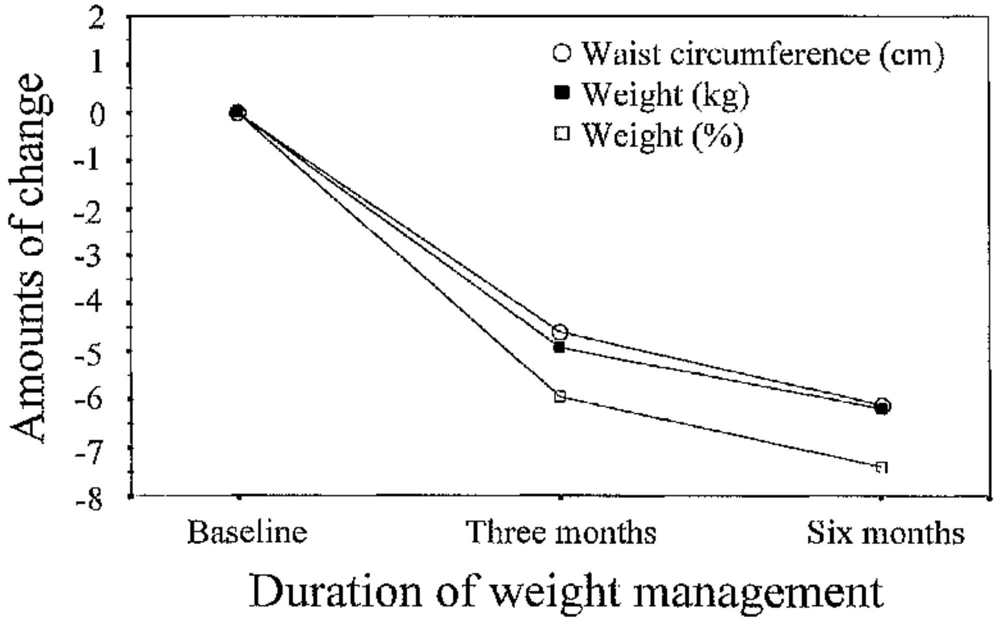


Figure 7.1.2. The pattern of change in weight loss and waist circumference reduction during six months of weight management in women. **Equation 1.** Predicting % weight loss from waist reduction (r^2 = 55.0%; SEE = 3.6 %weight): %Weight loss = 0.85 (95% confidence interval: 0.68 to 1.01) × Waist reduction (cm) - 2.09 (95% confidence interval: -3.40 to -0.77); **Equation 2.** Predicting waist reduction from % weight loss (r^2 = 55.0%; SEE = 3.2 cm): Waist reduction (cm) = 0.66 (95% confidence interval: 0.52 to 0.79) × %Weight loss - 1.35 (95% confidence interval: -2.54 to -0.16).

CHAPTER EIGHT

SKELETAL STRUCTURE: BODY DIMENSIONS IN RELATION TO METABOLIC DISORDERS: A CROSS-SECTIONAL SURVEY OF ADULTS

CONTENTS OF CHAPTER EIGHT PAGES

— 8.1 —

SKELETAL PROPORTIONS AND METABOLIC DISORDERS IN ADULTS

This section has been submitted for publication as

Han TS, Hooper J, Morrison CE, Lean MEJ. Skeletal proportions: the influences of age and gender with metabolic disorders in adults. (submitted).

ABSTRACT

Objective: The present study investigated the associations of stature, lower leg length (LLL) and demi-arm span (demi-AS) with major predisposing cardiovascular risk factors and coronary heart disease.

Study design and subjects: Cross-sectional study set at Glasgow Royal Infirmary of a subsample of 543 men and 646 women aged 25-66 years from the random MONICA sample.

Outcome measures: Blood pressure, plasma total cholesterol, diabetes mellitus and coronary heart disease (angina, angioplasty, heart attack, and coronary artery bypass graft).

Results: Results were adjusted for age, social class and smoking. Analysis of variance showed that in men, shortness of height, LLL or demi-AS were all associated with hypercholesterolaemia. Long LLL, high ratios of LLL:height or LLL:demi-AS was associated with diabetes mellitus. In women, shortness of height or LLL was associated with coronary heart disease, High ratio of demi-AS:height or low ratio of LLL:demi-AS was associated with coronary heart disease.

Conclusions: Short stature and limb lengths, and also altered skeletal proportions, which may reflect interrupted early growth, are associated with several metabolic disorders. Skeletal disproportion associates with diabetes in men and coronary heart disease in women.

Key words: age, coronary heart disease, diabetes mellitus, growth, stature, limb lengths.

INTRODUCTION

It has been suggested that growth failure *in utero* at different periods of pregnancy may result in altered body morphology (Barker, 1994). Early growth is clearly affected by under feeding in experimental animals (McCance, 1968). Disproportionate growth, e.g. longer or shorter limbs than expected for height occurs with delayed puberty (Tanner *et al*, 1971), but associations with metabolic disorders are not described. Different body proportions exist between adults of different races (Reeves *et al*, 1996), but improved standards of living with adequate nutrition has brought the body proportions of Japanese children nearer to the reference standards of the British (Tanner *et al*, 1982). Increase in height, or specifically leg length reflects improvement in health and growth (Tanner *et al*, 1982).

The present study investigated the sex and age differences in limb lengths relative to height and the associations of height, limb lengths and their relative proportions with hypertension, hypercholesterolaemia, diabetes mellitus and coronary heart disease.

METHODS

Subjects

From the Glasgow MONICA project to monitor cardiovascular disease in the West of Scotland (Morrison *et al*, 1997), a subsample of 543 men and 646 women had additional measurements of limb lengths.

Anthropometry

Weight to the nearest 100 g, height to the nearest 1 mm, waist circumference and hip circumference to the nearest 1 mm were measured according to standard protocols (WHO, 1995). Lower leg length (LLL) was measured to the nearest mm, as the distance from the top of the patellae to the soles lying supine, and demi-arm span (demi-AS) as the horizontal distance from the web space between middle and fourth fingers to the midpoint of the sternal notch to the nearest mm, in sitting position.

Physiological and biochemical assessment

A non-fasting venous blood sample was taken to determine plasma cholesterol. Systolic blood pressure and diastolic blood pressure, first and fifth Korotkoff sound respectively, were measured in sitting position after 15 minute rest. Coronary heart disease and known diabetes were assessed from questionnaire, defined as having angina and/or angioplasty and/or coronary heart bypass graft and/or heart attack. Diabetes mellitus was defined as having been told be doctor to have diabetes.

Statistical analyses

All analyses were performed using SPSS statistical package (Version 6.1, Chicago, USA). Analysis of variance (simple factorial) was carried out to determine the relationships between body lengths (independent variables) and metabolic disorders (dependent variables) with adjustments made for age, social class and smoking as possible confounding factors (covariates).

RESULTS

Table 8.1.1 shows the characteristics of subjects. Men and women had similar profiles of age and body mass index. Men were heavier and taller, with longer limbs and higher ratios of LLL:height, demi-AS:height and LLL:demi-AS than women. For a given limb length, men had lower height than women (**Figures 8.1.1a** & **b**), and for a given LLL, men had shorter demi-AS than women (**Figure 8.1.1c**).

Table 8.1.2 shows the proportions of hypertension, hypercholesterolaemia and coronary heart disease were significantly greater with shorter height in both sexes. The proportions of hypercholesterolaemia in men and coronary heart disease in women were elevated in those with shorter LLL.

Analysis of variance with adjustments for age, social class and smoking (**Table 8.1.3**) showed that in men, shortness of height, LLL or demi-AS were all associated with hypercholesterolaemia. Long LLL and high ratios of LLL:height and LLL:demi-AS were associated with diabetes mellitus. In women, shortness of height or LLL, high ratio of demi-AS:height or low ratio of LLL:demi-AS were all associated with coronary heart disease. For a given age, there were no differences in LLL:demi-AS ratio in men with or without coronary heart disease (**Figure 8.1.2a**). Women with coronary heart disease had lower ratio of LLL:demi-AS than women of similar age with coronary heart disease (**Figure 8.1.2b**). Compared to men without diabetes mellitus of similar age, men with diabetes mellitus had an elevated ratio of LLL: height (**Figure 8.1.3a**). Women with and without diabetes mellitus did not differ in the ratio of LLL:height (**Figure 8.1.3b**). There were no associations between other ratios of limb lengths to height with metabolic disorders in the present study.

DISCUSSION

In the present study, some body disproportions appear to relate to specific metabolic disease differently in each sex group. Men with high ratio of LLL:height or LLL:demi-AS (longer LLL than expected of height or demi-AS) were associated with diabetes mellitus, and women with a high ratio of demi-AS:height or low ratio of LLL:demi-AS (longer demi-AS than expected of height or lower LLL than expected of demi-AS) were associated with coronary heart disease. Skeletal growth in children has been monitored extensively (Tanner, 1989). It is well established that short stature is related to poor standards of living (Floud *et al*, 1990). Several recent reports have indicated that diabetes mellitus and impaired glucose tolerance are associated with short stature (**Chapter 5.5**; Brown *et al*, 1991; Mooy *et al*, 1995; Alvarsson *et al*, 1994; Williams *et al*, 1991), although McKeigue (1991) found no relationships between height and impaired glucose tolerance.

Classic studies of McCance (1968) have shown that protein and energy deficient diets have separate adverse effects on skeletal development in pigs. Low energy intake but balanced macronutrients resulted in a proportionally small stature. Adequate energy intake but lack of protein resulted in reduced skeletal structure but the size of the skull was preserved. It is possible that there may be hierarchical steps to sustain growth of vital organs, e.g. the nervous system, visceral organs and musculoskeletal system in that order, under conditions of stress or nutritional deprivation. Thus the musculoskeletal system, arguably the most expendable organ, may be amongst the first organ to be 'sacrificed'. Different limb lengths relative to height or relative to one another's length may reflect growth failure in early life. Under certain environmental conditions, subtle alterations in function of visceral organs and endocrine systems may become manifest as later development of metabolic disorders.

According to the 'thrifty phenotype' hypothesis (Hales and Barker, 1992) used to explain the relationships between early growth failure, abnormal organ morphology and function, and metabolic disorders, it is possible that musculoskeletal structure might be abnormally developed in people who were malnourished at critical times during *intra-uterine* development. In such adverse condition, blood (nutrients) may be diverted towards the brain at the expense of peripheral organs. This hypothesis is supported by several studies of blood distribution. Chronic hypoxia, produced by embolisation of the uteroplacental bed in fetal lamb, led to blood redistributed towards the brain (Reuss *et al*, 1982; Block *et al* 1984). Blood flow redistributed towards the brain has also been shown in asymmetrical growth retarded human foetuses, with large head relative to waist circumference (Al-Ghazali *et al*, 1989). In the most extreme situation, early malnutrition or stress will lead to low birth weight (known to relate to later metabolic diseases). The present results suggest that subtle alterations in skeletal size might be a subclinical indicator. The present study did not have information on subjects' body proportions or body weight at birth.

CONCLUSION

Short stature and limb lengths, and also altered skeletal proportions, which may reflect interrupted growth, are associated with several metabolic disorders. Skeletal disproportion associates with coronary heart disease in women and diabetes mellitus in men.

Table 8.1.1. Subjects' characteristics.

	Men (n = 543)			Women (n = 646)			
	Mean	SD	Range	Mean	SD	Range	P†
Age (years)	46.3	11.4	25.5-65.8	45.2	11.9	25.7-65.4	ns
Weight (kg)	78.8	13.9	42.0-130.7	66.8	13.5	42.7-124.6	***
Height (cm)	172.2	7.1	140.1-194.7	159.3	6.4	137.5-188.6	***
BMI (kg/m^2)	26.6	4.3	16.4-42.1	26.3	5.0	17.3-50.9	ns
LLL (cm)	51.5	2.9	40.5-59.5	47.1	2.7	40.2-57.6	***
Demi-AS (cm)	79.4	4.0	64.2-90.3	72.9	3.5	63.0-88.5	***
LLL to height ratio	0.299	0.010	0.269-0.334	0.296	0.010	0.256-0.341	***
Demi-AS:height ratio	0.461	0.014	0.410-0.510	0.457	0.013	0.405-0.497	***
LLL to demi-AS ratio	0.650	0.026	0.577-0.747	0.647	0.024	0.557-0.743	*
Systolic BP (mmHg)	133.1	18.9	82.0-252.0	123.7	19.4	88.8-211.0	***
Diastolic BP (mmHg)	81.7	11.5	51.0-129.0	73.7	11.3	35.0-121.0	***
Cholesterol (mmol/l)	5.99	1.12	3.00-9.92	5.94	1.25	3.26-10.17	ns

†Independent t-test for the differences in variables between men and women: ***P <0.001; P <0.05, ns = not significant; BMI = body mass index; LLL = lower leg length; AS = arm span; BP = blood pressure.

Table 8.1.2. Regression equations for predicting height from lower leg length and demi-arm span, and for predicting demi-arm span from lower leg length in 543 men and 646 women.

		Predicting height from lower leg length (LLL)
Equation 1a	Men	Height = 2.050 × LLL + 66.593
Equation 1b	Women	Height = 1.982 × LLL + 65.992
		Predicting height from demi-arm span (demi-AS)
Equation 2a	Men	Height = 1.442 × demi-AS + 52.978
Equation 2b	Women	Height = 1.459 × demi-AS + 57.768
		Predicting demi-arm span from lower leg length (LLL)
Equation 3a	Men	Height = 1.024 × LLL + 26.568
Equation 3b	Women	Height = 0.982 × LLL + 26.590

		95% confidence interval		r^2 (%)	SEE (cm)
		Independent variable	Constant		
Equation 1a	Men	1.929 to 2.171	60.334 to 72.851	69.9	3.91
Equation 1b	Women	1.862 to 2.102	60.342 to 71.642	67.6	3.64
Equation 2a	Men	1.353 to 1.530	50.730 to 64.807	65.4	4.17
Equation 2b	Women	1.367 to 1.552	46.200 to 59.755	62.4	3.97
Equation 3a	Men	0.940 to 1.108	22.229 to 30.906	54.70	2.7
Equation 3b	Women	0.907 to 1.057	23.051 to 30.128	56.69	2.28

Table 8.1.3. Proportions of metabolic disorders in 543 men and 646 women with different height and limb lengths.

	Hypertension		Hyper-cholesterolemia		Coronary heart disease		Diabetes mellitus	
	Men	Women	Men	Women	Men	Women	Men	Women
Height tertile 3	12.7	9.5	19.7	25.7	8.4	3.0	3.2	0.6
Height tertile 2	30.5	11.9	31.6	24.4	7.1	7.8	3.3	0.4
Height tertile 1	25.6	19.0	18.5	37.1	14.4	14.8	2.6	0.8
χ^2	14.8***	7.1*	13.0**	7.9*	5.1	14.7***	0.1	0.7
LLL tertile 3	16.8	12.5	21.3	28.1	9.8	4.5	4.6	1.3
LLL tertile 2	26.0	12.2	34.7	26.9	9.5	7.7	3.4	1.8
LLL tertile 1	25.9	15.7	33.7	32.2	10.5	13.2	0.4	2.4
χ^2	5.0	1.1	8.3*	1.3	0.1	8.1*	3.1	0.6
Demi-span tertile 3	18.8	10.7	22.9	33.1	9.9	6.1	3.5	1.4
Demi-span tertile 2	25.3	12.9	31.8	23.1	7.8	8.2	1.8	2.2
Demi-span tertile 1	24.2	16.7	34.4	31.7	12.3	11.1	3.9	1.9
χ^2	2.1	2.5	5.1	5.0	1.8	2.5	1.3	0.3

LLL = lower leg length; demi-AS = demi arm span.

Table 8.1.4. Analysis of variance adjusted for age, social class and smoking for the relationships between limb lengths and metabolic disorders in 543 men and 646 women.

							Ratios					
	Height		LLL		Demi-AS		LLL:height		demi-AS: height		LLL: demi-AS	
	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*	F	*P*
Men												
Hypertension	1.7	0.190	0.4	0.515	0.4	0.524	0.2	0.650	0.5	0.492	0.0	0.855
Hypercholestrolaemia	9.8**	0.002	5.3*	0.021	6.2*	0.013	0.0	0.840	0.0	0.965	0.0	0.868
Coronary heart disease	0.1	0.718	0.0	0.953	0.1	0.747	0.1	0.740	0.0	0.915	0.1	0.790
Diabetes mellitus	1.0	0.326	4.1	0.044	0.2	0.643	5.3*	0.022	0.2	0.641	5.7*	0.017
Women												
Hypertension	0.8	0.362	0.1	0.803	1.0	0.308	0.5	0.490	0.1	0.729	0.8	0.379
Hypercholestrolaemia	0.0	0.988	1.1	0.302	0.7	0.390	3.3	0.070	1.9	0.169	0.3	0.594
Coronary heart disease	6.7*	0.010	6.2*	0.013	1.0	0.307	1.0	0.323	4.3*	0.039	5.9*	0.016
Diabetes mellitus	0.1	0.796	1.2	0.267	0.2	0.671	2.4	0.123	0.0	0.840	1.1	0.294

$^{**}P < 0.01$; $^{*}P < 0.05$; LLL = lower leg length; demi-AS = demi arm span.

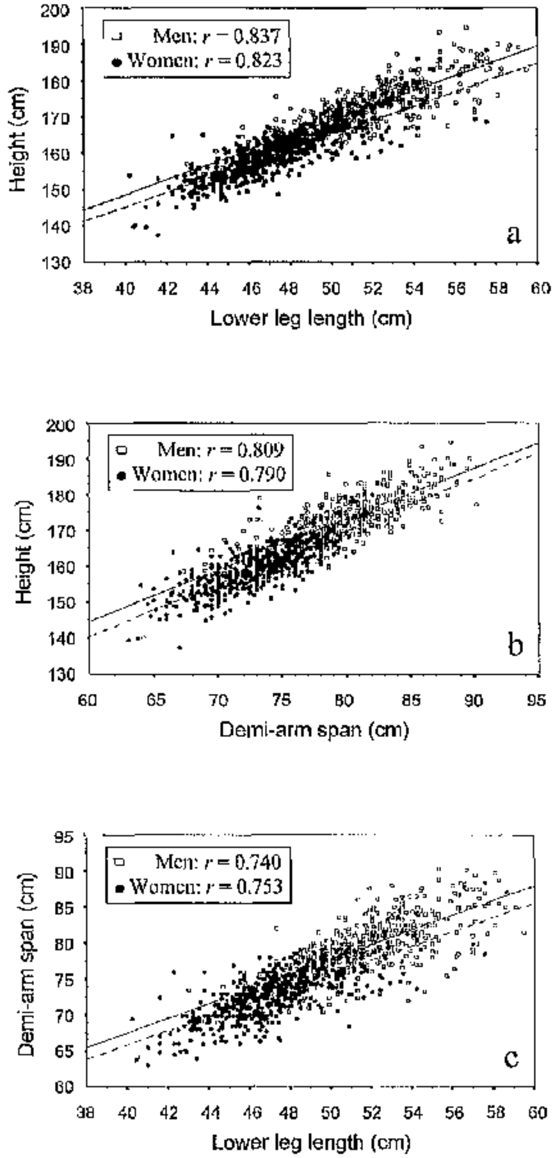


Figure 8.1.1. Plots and regression lines between height and lower leg length (a), between height and demi-arm span (b) and between lower leg length and demi-arm span (c) in 543 men (□, solid line) and 646 women (●, dashed line).

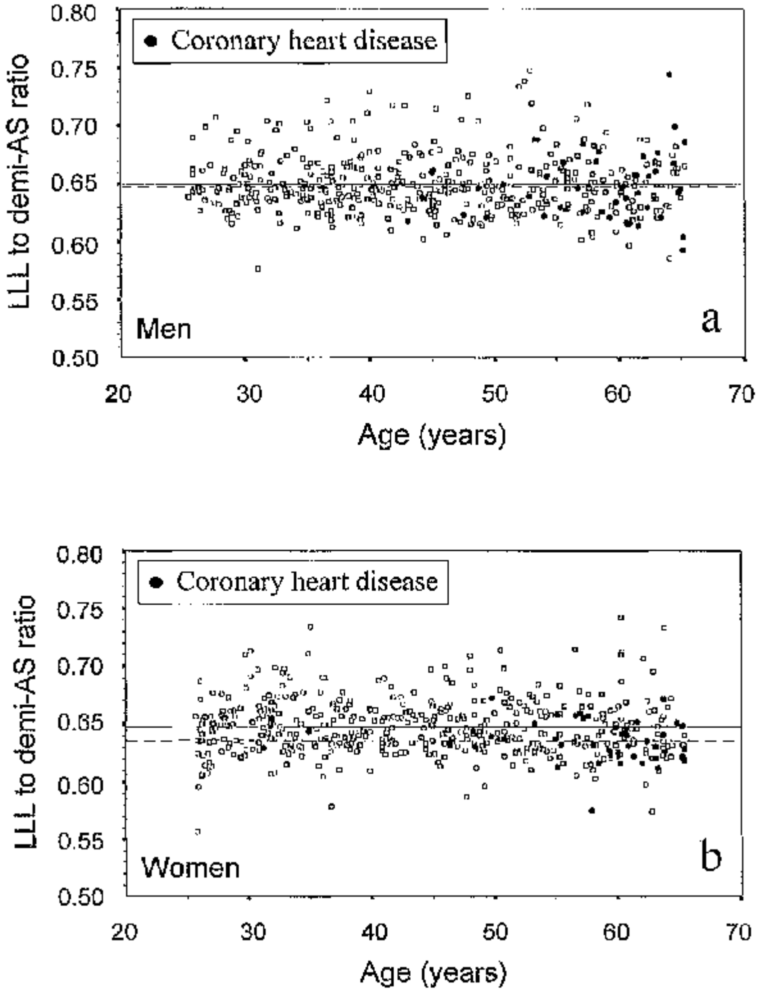


Figure 8.1.2. Distribution of coronary heart disease (●) in different ratios of lower leg length to demi-arm span (LLL to demi-AS) relative to age in 543 men (a) and 646 women (b).

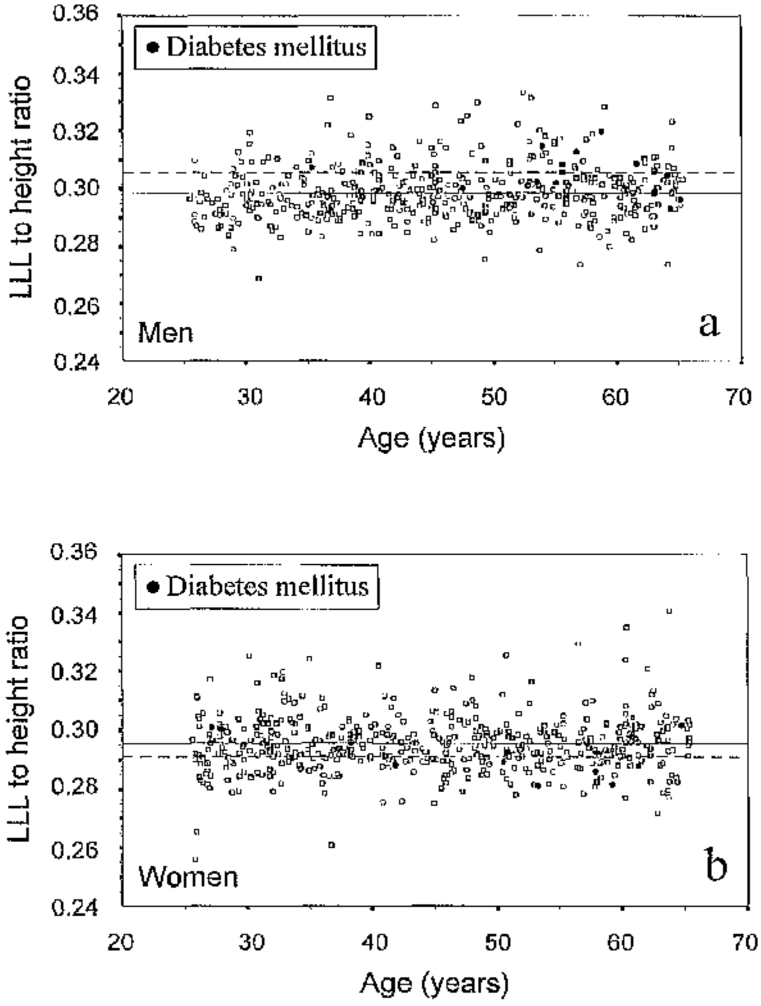


Figure 8.1.3. Distribution of diabetes mellitus (●) in different ratios of lower leg length height (LLL to height) relative to age in 543 men (a) and 646 women (b).

CHAPTER NINE

NATURAL SPORTING ABILITY IN RELATION TO BODY MORPHOLOGY AND HEALTH IN LATER LIFE: A RETROSPECTIVE FOLLOW-UP STUDY

CONTENTS OF CHAPTER NINE **PAGES**

— 9.1 —

NATURAL SPORTING ABILITY, BIRTH WEIGHT AND PREDISPOSITION TO CARDIOVASCULAR DISORDERS

This section has been submitted for publication as

Lean MEJ, **Han TS**. Natural sporting ability, birth weight and predisposition to cardiovascular disorders. (submitted).

ABSTRACT

Objective: To test the hypothesis that people with a natural ability in "power sports" (a presumed marker for predominance of type 2, glycolytic muscle fibres) might have increased risks of coronary heart disease (CHD) compared to those with a natural ability in "endurance sports" (as a marker for predominance of type 1, oxidative muscle fibres), and that early growth as reflected by birth weight might influence these relationships.

Design and subjects: Retrospective self-reported study of 231 male former soldiers, aged 34-87 years who had undergone a course in physical training in the Army School of Physical Training, Aldershot, (UK).

Outcome measures: Subsequent cardiovascular disorders.

Results: The proportions who had CHD, defined as angina and/or coronary angioplasty and/or coronary artery bypass graft and/or heart attack were 18.7% in power group compared to 9.7% in endurance group (difference: $\chi^2 = 3.9$, $P = 0.05$). The proportions with CHD and/or risk factors rose to 39.3% in power group compared to 25.8% in endurance group (difference: $\chi^2 = 4.8$, $P = 0.03$). Birth weight related negatively to CHD ($\beta = -0.18$, $P = 0.38$), and to CHD and/or risk factors ($\beta = -0.31$, $P = 0.03$). Men in the power group with birth weights below median were more likely to develop CHD and/or risk factors (age, current body mass index, and lifestyle factors adjusted odds ratio = 10.5, 95% confidence interval: 1.9 to 59.5), compared to men in the endurance group with birth weights above median.

Conclusion: Men with a natural ability in power sports are at increased risk of developing cardiovascular disorders when compared to men with a natural ability in endurance sports. Low birth weight has an independent additive effect. These findings suggest the hypothesis that a predominance of type 2, glycolytic muscle fibres, presumably of genetic origin, predisposes to cardiovascular disorders.

INTRODUCTION

In the history of modern medicine, coronary heart disease (CHD) and related disorders including hypertension and dyslipidaemia have probably been more intensively studied than most other diseases. Recent epidemiological studies have produced compelling evidence for associations of growth retardation in early life, using birth weight as the marker, with cardiovascular disorders and other metabolic diseases (Barker *et al*, 1992). Barker (1994) has proposed the use of the 'thrifty phenotype' and 'programming' hypotheses as ways to explain these relationships.

Several studies have suggested that features related to metabolic syndrome may be associated with a muscle metabolism which tends to rely predominantly on the glycolytic pathway (as opposed to oxidative pathway). Type 2b, glycolytic, white muscle fibres are less sensitive to insulin action than type 1, oxidative, red muscle fibres in rats (Bonen *et al*, 1981; James *et al*, 1985; Richter *et al*, 1984). In a study of non-diabetic Caucasian (n = 23) and Pima Indian (n = 41) men, Lillioja *et al* (1987) have shown that insulin action correlated positively with the proportion of type 1 fibres (r = 0.29, P = 0.02) and negatively with the proportion of type 2b muscle fibres (r = -0.38, P = 0.003). In women, Krotkiewski *et al* (1990) found that type 2b muscle fibres correlated positively (P <0.05) with fasting insulin and glucose. Men and women with NIDDM (Mårin *et al*, 1994) and women with Cushing's syndrome (Rebuffé-Scrive *et al*, 1988) have significantly higher proportions of type 2b muscle fibres than 'healthy' controls. All the aforementioned studies of muscle fibres and related metabolic disorders showed type 2b muscle fibres were associated with another feature related to metabolic syndrome, abdominal fat distribution (indicated by high ratio of waist to hip or to thigh circumference). Men with intra-abdominal fat accumulation (measured by computerised tomography), associated with metabolic disorders including raised insulin concentration and blood pressure, have low capacities for endurance (aerobic) exercise (Seidell *et al*, 1989a). The range of type 1 fibres varies from 10% to 90% between individuals (Saltin and Gollnick, 1983). Men tend to have higher proportion of type 2 muscle fibres than women (Simoneau *et al*, 1989). Athletes who specialise in aerobic sports, such as marathon runners, tend to have high proportion of slow twitch (type 1) muscle fibres, while those who specialise in anaerobic sports, such as sprinters or jumpers, tend to have high proportion of fast twitch (type 2a and 2b) fibres (Åstrand and Rodahl, 1986).

Hypothesis

The present study aimed to test the hypothesis that subjects with a natural ability in power sports (a presumed marker for type 2 muscle fibre predominance) might have increased risks of developing cardiovascular disorders compared to those with a natural ability in endurance sport (as a marker for type 1 muscle fibre predominance), and that the relationships may be influenced by birth weight, reflecting early growth.

METHODS

Subjects and study design

British male former soldiers who had undergone a course in physical training at the Army Physical Training School, Aldershot were studied retrospectively on the basis of their interest in physical activity and probable relative homogeneity in terms of health, fitness, dietary and other lifestyle behaviours. Five hundred names of former army soldiers were selected randomly from the computer database, and 231 (response rate = 46.2%) of these subjects aged 34 to 87 years returned self-completed questionnaires.

Questionnaires

Questionnaires were designed based on the Glasgow MONICA Personal Health Questionnaire (Morrison *et al*, 1997). Lists of events associated with endurance and another associated with power sports were presented. Subjects were asked to select only one list which best described the events for which they thought they had better natural ability when aged between 16-40 years (**Table 9.1.1**). This information provided two separate groups of subjects, 'endurance' and 'power' (Dirix *et al*, 1991) for analysis.

Subjects provided self measured anthropometric variables, and were asked to provide their birth weight if known, confirmed with elder relatives if possible. The accuracy of reported birth weight could not be validated in the present study, but birth weight self-reported by women aged 27-44 years (Troy *et al*, 1996) or recalled from mothers (Troy *et al*, 1996; Lumey *et al*, 1994) or both parents (Pless and Pless, 1995) has been found to be valid for epidemiological analysis. The questionnaires contained lists of medical history including angina, coronary angioplasty, coronary artery bypass graft, heart attack, hypertension, hypercholesterolaemia, diabetes mellitus, and medications for these conditions, i.e. aspirin for heart disease, medications for angina, high blood pressure and high cholesterol. Lifestyle factors were also reported including smoking, alcohol drinking, current physical activity level, education. Recent dietary consumption was obtained using a short food frequency questionnaire (developed for the Scottish Health Survey), including meat, fish, potatoes/rice/pasta, and raw vegetables consumption.

Statistical analyses

Clusters of outcome measures were made for *coronary heart disease* (CHD) (n = 32, prevalence = 13.9%), defined as having angina and/or coronary angioplasty and/or coronary artery bypass graft and/or heart attack), and for *CHD and/or hypertension and/or hypercholesterolaemia and/or diabetes mellitus, and/or medications for these conditions* (CHD and/or risk factors) (n = 74, prevalence = 33.0%). Statistical analyses were performed using SPSS Version 6 (Chicago, USA). Independent t-tests were used to test for the differences between groups' characteristics, and Chi-square tests for the differences in prevalences of cardiovascular disorders. Linear multiple regression analysis was used to determine the relationships between birth weight and CHD or CHD and/or risk factors, with age adjustment. Logistic regression was performed to test the interaction between sporting ability and birth weight in relation to cardiovascular disorders (CHD or CHD and/or risk factors) with age adjustment. The relative risk of cardiovascular disorders was estimated by odds ratios in logistic regression analysis, adjusted for age, body mass index, lifestyle factors and, and types of food consumed. Ninety-five percent confidence interval limits were calculated as the exponential of (β $\pm 1.96 \times$ standard error) (Kleinbaum *et al*, 1982).

RESULTS

Table 9.1.2 shows that for the whole sample (n = 231), age and height did not differ significantly between endurance and power groups, and similar numbers of subjects reported natural ability for power or endurance events. The power group had higher body weight and body mass index when they were in the army and at the time of the study. There were 111 subjects who provided a reported birth weight. Ten subjects (6 endurance and 4 power) reported that they had been born prematurely, and were excluded in analyses involving birth weight. In the remaining 101 subjects, there were no significant differences in age or any anthropometric variable between endurance and power groups (**Table 9.1.2**). There were no differences in proportions of current lifestyle behaviours between endurance and power groups (**Table 9.1.3**).

Table 9.1.4 shows that compared to the endurance group, there was a tendency for higher prevalences in the power group in all cardiovascular conditions, predisposing risk factors, medications for these cardiovascular disorders. There were no age differences between endurance and power groups who had CHD (age = 70.3 versus 70.5, P = 0.97) or CHD and/or risk factors (age = 66.7 versus 66.0, P = 0.79). Compared to endurance group, the power group had higher risk of CHD (P = 0.05) and CHD and/or risk factors (P = 0.03) (**Table 9.1.5, Figure 9.1.1**).

Linear multiple regression analysis with age adjustment, showed that birth weight was negatively related to CHD (β = -0.18, P = 0.38), and to CHD and/or risk factors (β = -0.31, P = 0.03), supporting previous findings of Barker *et al* (1992). Birth weight was therefore incorporated as a possible confounder in the analysis of the relationships of CHD or CHD and/or risk factors with natural sporting ability. There were no interactions (age adjusted) between birth weight and natural sporting ability in relation to cardiovascular disorders (results not shown).

Table 9.1.6 shows that compared to the endurance group, with age and birth weight adjustments, the power group had significant risks of CHD and/or risk factors (P <0.01).

The relationships between sporting ability and CHD and/or risk factors were analysed separately in two groups of birth weight above and below the median (3402 g) (**Table 9.1.2, Tables 9.1.6 & 9.1.7**). **Figure 9.1.2** shows that the prevalence of CHD and/or risk factors was higher for the power group than the endurance group for any birth weight. The lowest prevalence of CHD and/or risk factors was observed in the endurance group with large birth weight, and highest in the power group with low birth weight. Those in the power group with large birth weight had higher prevalence of CHD and/or risk factors than those in endurance group with low birth weight. Similar findings were observed for association between sporting ability with existing CHD (data not shown).

Endurance subjects with large birth weight were used as the reference group. After age adjustment, power subjects with small birth weight had the highest odds ratio of CHD or CHD and/or risk factors (**Table 9.1.6**). Endurance subjects with small birth weight were at lower risk than power subjects with large birth weight. There were slight changes in these relationships when adjustments were made for current body mass index and lifestyle factors (**Table 9.1.7**). The additional adjustment for current frequency consumption of meat, carbohydrate foods, and raw vegetables changed the odds ratio to 10.7 (95% confidence interval: 1.8 to 61.4, P <0.01) for CHD and/or risk factors.

DISCUSSION

The present study has produced novel data to suggest that men with a natural ability in power sports, as a presumed marker for type 2 muscle fibre predominance, had increased incidence of cardiovascular disorders in later life. A low birth weight, indicating early growth retardation, had an independent additive effect. These findings suggest that increased glycolytic, type 2 muscle fibres predispose to the development of cardiovascular disorders. This conclusion from the present study is supported by previous studies showing associations of increased type 2 muscle fibres with features related to the metabolic syndrome including diminished insulin action (Lillioja *et al*, 1987; Krotkiewski *et al*, 1990), NIDDM (Mårin *et al*, 1994), Cushing's syndrome (Rebuffé-Srive *et al*, 1988), and abdominal fat distribution (Lillioja *et al*, 1987; Rebuffé-

Srive *et al*, 1988; Seidell *et al*, 1989a; Krotkiewski *et al*, 1990). Although it is also well established that physical activity improves most cardiovascular risk factors, and delays CHD (Morris *et al*, 1980; Morris *et al*, 1990; Paffenbarger *et al*, 1986), it has not been possible to separate the effects of training from underlying physiological factors.

Subjects in the present study were all sports enthusiasts, and mostly homogenous in terms of their standard physical training programme, their diet exposure, and other lifestyle behaviours when they were in the Army. There was no evidence for differences in their current physical activity, cigarette smoking, alcohol drinking, educational level or selected dietary components currently consumed **(Table 9.1.3)**. The risks of developing cardiovascular disorders in those with natural ability in power sports with small birth weight remained significantly higher than those with a natural ability in endurance sports with large birth weight, even when other possible confounding factors including age, current body mass index, smoking, current leisure activity, alcohol drinking and education were made. Additional adjustments for current consumption frequencies of meat, carbohydrate foods (potatoes/rice/pasta) and raw vegetables did not change the odds ratios significantly.

The results from the present study cannot explain how natural ability in power sports led to the increased risk of cardiovascular disorders, but muscle composition and sporting ability are probably genetically determined. As Klissouras (1976) put it: "Natural tendency inevitably asserts itself", most of men in the present study (about 95%) who considered themselves to have natural ability in one type of sport actually performed sport events of that same type. The quote "endurance (or power) athletes are born, not made" is fittingly supported by studies of monozygotic and dizygotic twins (Klissouras, 1971 & 1976; Klissouras *et al*, 1973; Komi *et al*, 1977) to determine the heritability estimate. Heritability estimate has been found to be 93% for maximum oxygen uptake, 81% for maximum blood lactate, and 86% for maximum heart rate (Klissouras, 1971). Komi *et al* (1977) have shown that heritability estimate for percentage type 1 muscle fibres of the vastus lateralis muscle was 99.5% in males and 92.8% in females.

Furthermore, no changes in muscle fibre composition have been observed by either endurance (Gollnick *et al*, 1973) or strength training (Thorstensson *et al*, 1975).

The measurements of natural sporting ability, cardiovascular disorders and birth weight were self-reported. It is possible that some of the answers were unreliable, leading to random errors and probably underestimating the 'true' associations between variables (bias towards the null hypothesis). It seems unlikely that the answers on natural sporting ability and birth weight were influenced by disease state (recall bias).

The observations of the associations of type 2b muscle fibres with abdominal fat distribution (Lillioja *et al*, 1987; Rebuffé-Scrive *et al*, 1988; Krotkiewski *et al*, 1990) and poor endurance with intra-abdominal fat accumulation (Seidell *et al*, 1989a), and the associations of low birth weight with abdominal fat distribution in men (Law *et al*, 1992) and in women (Han *et al*, 1995a) suggest possible mechanisms linking abnormal fat metabolism and type 2 muscle fibres with early growth retardation (**Figure 9.1.3**). The present study found no interactions between birth weight and natural sporting ability in relation to cardiovascular disorders. Natural ability in power sports and low birth weight had an additive effect on the development of coronary heart disease and related disorders. It has been suggested that malnutrition at different period of fetal growth has an adverse effect on organs differently, depending on the time when cell differentiation for a particular organ is most prolific (Barker, 1994). Thus muscle fibre composition may be influenced by growth failure at different time during development *in utero*. The present study did not have this information.

CONCLUSIONS

Men with a natural ability in power sports are at higher risk of developing cardiovascular disorders than those with a natural ability in endurance sports, and low birth weight has an independent additive effect. The results from the present study suggest that muscle fibre composition may play a role in developing cardiovascular disorders in later life.

Table 9.1.1. Question and lists of 'endurance' and 'power' sport events adapted from The Olympic Book of Sports Medicine (Dirix *et al*, 1991).

Between **16-40 years**, was your NATURAL ABILITY highest for **endurance sports** <u>or</u> **power sports**? please tick ONE BOX ONLY

ENDURANCE SPORTS	☐	**<u>or</u>**	POWER SPORTS	☐

Examples of **endurance sports**	Examples of **power sports**
Running 1 mile or more	100 yard dash
Cross country	Sprint running 100 m, 200 m
Cross-country skiing	Long jump
Triathlon	High jump
Road cycling	Weight lifting
Orienteering	Discuss throwing
Long distance swimming	Shot putting
Canoeing	Javelin throwing
Walking long distance	Pole vaulting

Table 9.1.2. Characteristics of 231 male former soldiers. All anthropometric measures were converted to metric units from reported empirical units.

	Natural ability in 'endurance sports' (n = 124)			Natural ability in 'power sports' (n = 107)			
	Mean	SE	Range	Mean	SE	Range	P*
All subject							
Age (years)	59.7	1.2	34.4-86.8	62.4	1.2	37.3-87.3	0.11
Current weight (kg)	75.0	0.7	44.5-103.9	77.4	0.8	60.3-101.6	0.03
Height (cm)	173.9	0.5	158.8-190.5	174.1	0.7	152.4-193.0	0.78
Current BMI (kg/m^2)	24.8	0.2	15.8-34.8	25.5	0.2	21.5-31.9	0.04
Weight in army (kg)	69.6	0.6	54.0-82.6	71.3	0.6	54.0-101.6	0.05
BMI in army (kg/m^2)	23.0	0.2	19.1-27.8	23.5	0.2	19.1-30.7	0.03
Those with reported birth weight, excluding those born prematurely (n = 10)							
		n = 52			n = 49		
Age (years)	58.2	1.8	34.4-83.9	60.8	1.7	37.3-83.8	0.29
Current weight (kg)	76.6	0.9	61.0-95.3	79.0	1.2	60.3-101.6	0.13
Height (cm)	174.6	0.8	163.8-190.5	175.3	1.1	160.0-193.0	0.53
Current BMI (kg/m^2)	25.2	0.3	20.8-30.1	25.7	0.4	21.7-31.9	0.24
Weight in army (kg)	70.8	0.8	57.2-82.6	72.0	1.0	54.4-101.6	0.38
BMI in army (kg/m^2)	23.3	0.2	19.2-26.1	23.5	0.3	19.5-28.8	0.60
Birth weight (kg)	3.39	0.08	1.36-4.59	3.54	0.11	1.42-5.44	0.25

*Independent t-test for the differences in characteristics between groups; BMI = body mass index.

Table 9.1.3. Comparison of lifestyle factors and dietary intake between men with natural ability in 'endurance sports' versus 'power sports'.

	Proportions (%)			
	'Endurance group' ($n = 124$)	'Power group' ($n = 107$)	χ^{2*}	P*
Exercise at least once a week	61.0	61.7	0.01	0.91
Currently smoking	12.9	11.2	0.15	0.70
Alcohol drinking ≥3 units/day	18.5	20.6	0.15	0.70
Education level at secondary or below	39.0	42.9	0.35	0.56
Meat eaten ≥2 times a week	79.0	80.4	0.06	0.80
Potatoes, pasta or rice eaten ≥2 times a week	87.1	88.8	0.15	0.70
Raw vegetables eaten ≥2 times a week	70.2	74.8	0.61	0.44

*Chi-square test for the differences in proportions between the two groups.

Table 9.1.4. Prevalence of coronary heart disease, predisposing risk factors and medications for these conditions, and family history of heart disease in 124 men with a natural ability in 'endurance sports' and 107 men in 'power sports'.

	Prevalence					
	'Endurance sports' ($N = 124$)		'Power sports' ($N = 107$)			
	n	%	n	%	χ^{2*}	P*
List 1: Coronary heart disease						
Angina	3	2.4	9	8.4	4.19	0.04
Coronary angioplasty	1	0.8	2	1.9	0.51	0.48
Coronary artery bypass graft	1	0.8	5	4.7	3.39	0.07
Heart attack	11	8.9	17	15.9	2.65	0.10
List 2: Predisposing risk factors						
Hypercholesterolaemia	9	7.3	14	13.1	2.17	0.14
Hypertension	16	12.9	19	17.8	1.05	0.31
Diabetes mellitus	3	2.4	3	2.8	0.03	0.86
List 3: Medications						
Aspirin for the heart disease	11	8.9	13	12.1	0.66	0.42
Medication for angina	2	1.6	5	4.7	1.83	0.18
Medication for hypertension	4	3.2	12	11.2	5.69	0.02
Medication for hypercholesterolaemia	2	1.6	6	5.6	2.74	0.10
Medication or diet for diabetes	2	1.6	2	1.9	0.02	0.88
Clusters						
CHD†	12	9.7	20	18.7	3.91	0.05
CHD and/or risks and/or medications‡	32	25.8	42	39.3	4.77	0.03

*Chi-square test for the differences in prevalence between the two groups; †coronary heart disease = angina and/or coronary angioplasty and/or coronary artery bypass graft and/or heart attack (**list 1**); ‡coronary heart disease (**list 1**) and/or predisposing risks factors (**list 2**) and/or medications (**list 3**).

Table 9.1.5. Odds ratios for coronary heart disease and coronary heart disease and/or predisposing risk factors and/or medications for these conditions, in 107 men with a natural ability in 'power sports' compared to 124 men with a natural ability in 'endurance sports'.

	Odds ratio	95% CI	*P*
Dependent variable: coronary heart disease†			
Predictors:			
'Endurance group' (reference)	1.00	___	___
'Power group'	2.15	1.00, 4.63	0.05
Dependent variable: coronary heart disease and/or risks and/or medications‡			
Predictors:			
'Endurance group' (reference)	1.00	___	___
'Power group'	1.86	1.06, 3.25	0.03

†Coronary heart disease = angina and/or coronary angioplasty and/or coronary artery bypass graft and/or heart attack (**Table 9.1.4, list 1**); ‡coronary heart disease and/or predisposing risks factors and/or medications (**Table 9.1.4, lists 1-3**).

Table 9.1.6. Odds ratios for coronary heart disease and/or predisposing risk factors and/or medications for these conditions, in subjects with birth weight reported (49 men with a natural ability in 'power sports' compared to 52 men with a natural ability in 'endurance sports'), adjusted for age.

	Odds ratio	95% confidence interval	*P*
Dependent variable: CHD and/or predisposing risk factors and/or medications*			
Predictors:			
'Endurance group' (reference)	1.00	———	——
'Power group'	4.73	1.75, 12.80	0.00
Birth weight above median† (reference)	1.00	———	——
Birth weight below median†	2.70	1.01, 7.17	0.05
Dependent variable: CHD and/or predisposing risk factors and/or medications*			
Predictors (combined terms):			
'Endurance' and birth weight above median (reference)	1.00	———	——
'Endurance' and birth weight below median	2.31	0.52, 10.29	0.27
'Power' and birth weight above median	4.08	0.95, 17.59	0.06
'Power' and small birth weight below median	12.30	2.40, 63.00	0.00

*Coronary heart disease and/or predisposing risks factors and/or medications (**Table 9.14, lists 1-3**); †median value of birth weight = 3402 g.

Table 9.1.7. Odds ratios for coronary heart disease and/or predisposing risk factors and/or medications for these conditions, in subjects with birth weight reported (49 men with a natural ability in 'power sports' compared to 52 men with a natural ability in 'endurance sports'), adjusted for age, education, current body mass index, smoking, alcohol drinking and physical activity.

	Odds ratio	95% confidence interval	*P*
Dependent variable: CHD and/or predisposing risk factors and/or medications*			
Predictors:			
'Endurance group' (reference)	1.00	———	——
'Power group'	4.31	1.48, 12.55	0.01
Birth weight above median† (reference)	1.00	———	——
Birth weight below median†	2.65	0.77, 9.17	0.07
Dependent variable: CHD and/or predisposing risk factors and/or medications*			
Predictors (combined terms):			
'Endurance' and birth weight above median (reference)	1.00	———	——
'Endurance' and birth weight below median	1.83	0.38, 8.78	0.45
'Power' and birth weight above median	3.01	0.64, 14.21	0.16
'Power' and small birth weight below median	10.51	1.86, 59.46	0.01

*Coronary heart disease and/or predisposing risks factors and/or medications (**Table 9.14, lists 1-3**);
†median value of birth weight = 3402 g.

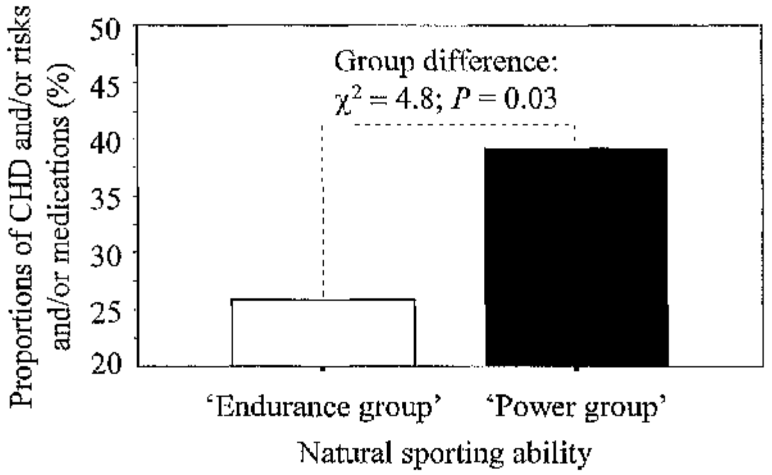


Figure 9.1.1. Proportions of subjects with coronary heart disease and/or predisposing risks and/or medications in groups with natural ability in endurance or power sports.

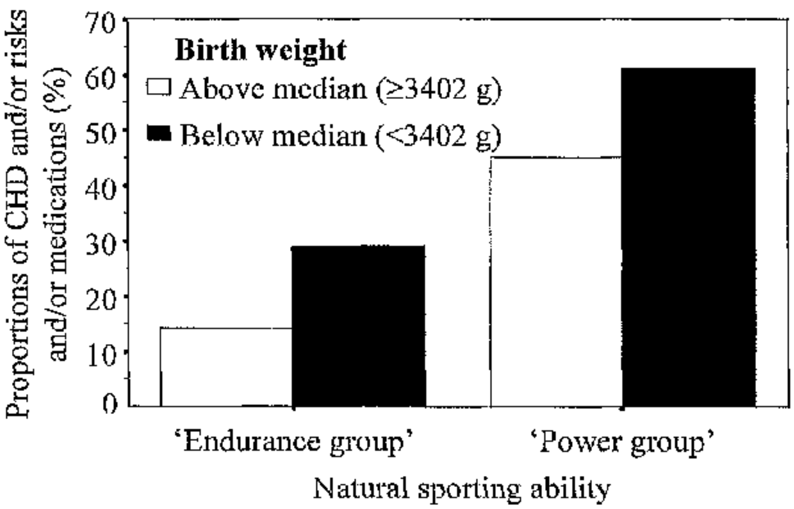


Figure 9.1.2. Proportions of subjects with coronary heart disease and/or predisposing risks and/or medications in groups with natural ability in endurance or power sports, with large or small birth weight.

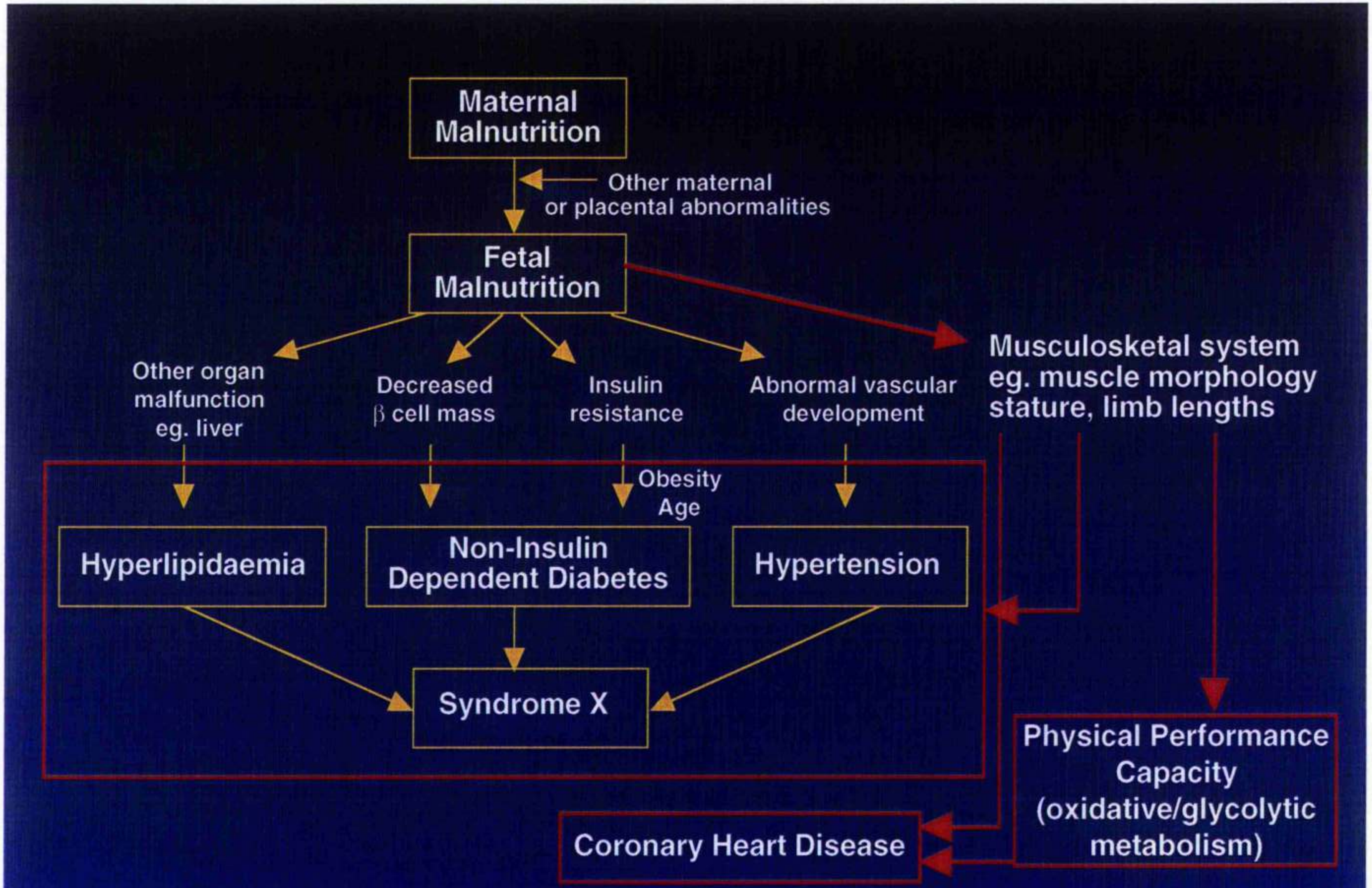


Figure 9.1.3. Expansion of the 'thrifty phenotype' hypothesis (Barker, 1994), with results from the present thesis (red).

|| CHAPTER TEN

SELF ASSESSMENT OF BODY MORPHOLOGY FOR HEALTH PROMOTION

|| CONTENTS OF CHAPTER TEN PAGES

— 10.1 —

DEVELOPMENT AND EVALUATION OF THE 'WAIST WATCHER' TAPE MEASURE FOR ASSESSMENT OF WAIST CIRCUMFERENCE IN FREE LIVING SUBJECTS

This section has been submitted for publication as

<u>**Han TS**</u>, Morrison CE, Lean MEJ. 'Waist Watcher' tape measure as a screening tool to identify people at increased health risk through intra-abdominal fat accumulation. (in preparation).

ABSTRACT

Objective: To evaluate the accuracy of self-reported and self-measured waist by subjects using the 'Waist Watcher' tape measure, designed to monitor waist circumference.

Study design and setting: Random sample of 101 men and 62 women aged 28-67 years in a cross-sectional study, based at Glasgow Royal Infirmary.

Outcome measures: Self-reported and self-measured waist circumference, and self-classification according to the previously defined waist Action Level 1 (94 cm in men, 80 cm in women) and Action Level 2 (102 cm in men, 88 cm in women), and waist circumference measured by investigator using the 'Waist Watcher' tape measure.

Results: Waist circumference measured by the investigator was used as the reference method. The mean errors (95% confidence interval limits of agreement) for self-reported waist (self-reported minus reference) were -7.1 cm (-21.5 to 7.2) in men and -5.2 (-22.2 to 11.9) in women, and for subjects' self-measured waist made by the 'Waist Watcher' (self-measured minus reference) were -0.6 cm (-6.5 to 5.4) in men and -0.6 (-5.3 to 4.5) in women. Classifications using waist Action Level 1 or Action Level 2 by the investigator were used as the reference method. Self-reported waist circumference of men and women, respectively, would be classified correctly in different categories based on Action Level 1 with sensitivities of 57.4% and 74.3%, and specificities of 92.5% and 100%, and Action Level 2 with sensitivities of 32.4% and 27.8%, and specificities of 98.5% and 93.2%. Using the 'Waist Watcher' with different colour bands based on the Action Levels to assess waist size, subjects classified themselves into correct categories according to Action Level 1 with sensitivities of 100% and 94.3%, and specificities of 95.0% and 96.3%, and according to Action Level 2 with sensitivities of 97.1% and 100%, and specificities of 100% for both sexes. Only 2% of the sample misclassified themselves into the wrong categories of waist circumference Action Levels.

Conclusions: 'Waist Watcher' tape measure offers advantages over self-reported home-assessed measurement of waist circumference, and may be used as a screening tool for self-classifying the risk of ill health through intra-abdominal fat accumulation.

Key words: abdominal fat distribution, health promotion, waist circumference.

INTRODUCTION

Obesity, a wholly preventable disease, is increasing 2-5% per decade and has now reached an epidemic proportion, affecting more than 15% in most Western countries (Seidell *et al*, 1995a; Kuczmarski *et al* 1994). On the basis of current epidemiology and trends, targets set by health authorities to reduce the rising prevalence by the year 2000 will inevitably fail.

Health promotion and bathroom scales have hitherto made no impact on the upward trend in overweight and obesity. Obesity is partly explained by genetic predisposition but also requires an appropriate environment, e.g. over-provision of food without the need for physical activity, to express itself (Bouchard *et al*, 1990; Stunkard *et al*, 1990). The recent success in cloning of human obese gene responsible for producing leptin (Zhang *et al*, 1994) has caused great excitement amongst the scientific community and the popular press, but the world is still waiting for its successful application in obesity treatment. Although genetic predisposition is a logical necessity to explain why only some people become obese, mechanisms are not yet clear and 'gluttony and sloth' (Prentice and Jebb, 1995) are frequent victim-blaming explanations.

Fatter than ever, people in the UK and other urban societies are increasingly suffering from a catalogue of symptoms of obesity and secondary diseases, including tiredness, sweating, breathlessness, back pain, arthritis, menstrual and fertility disorders, cardiovascular disease, non-insulin-dependent diabetes mellitus and several major cancers. These lead to impaired quality of life, depression and premature death. Recent estimates of costs *per annum* for treating obesity are 195 million pounds in Britain (Office of Health and Economics, 1994), and 70 billion dollars in the United States (Institute of Medicine, 1995). The limited success in reversing the increasing trends in obesity attributable to the lack of public awareness of self-assessment of obesity and a sense of medical impotence in management, urges the development of new strategies. Clinical guidelines for improved medical management are available in several countries

(Institute of Medicine, 1995; Scottish Intercollegiate Guidelines Network, 1996, German Society of Obesity Research, 1995).

Given the complex interactions between cosmetic and health impact of body shape and size, a waist circumference reduction is a rewarding consequence of slimming and has been suggested as a better motivator than weight change (Egger *et al*, 1995). We have recently proposed the use of waist circumference as a simple method for detecting overweight (body mass index) and central fat distribution (waist to hip ratio) (**Chapter 4.1**; Lean *et al*, 1995), and for identifying people with cardiovascular risk factors (**Chapter 4.2**; Han *et al*, 1996c). The figures for waist circumference Action Level 1 (94 cm in men, 80 cm in women) and Action Level 2 (102 cm in men, 88 cm in women) were identified for health promotion to alert people to increasing health risks. A patent 'Waist Watcher' tape measure was manufactured specifically for the present study based on these Action Levels. The present study was designed to evaluate the 'Waist Watcher' tape measure (**Figure 10.1.1**) in self-measurement and self-classification of waist circumference categories according to the Action Levels.

METHODS

Subjects

A random sample of subjects who participated in the MONICA 4 project one year previously were recalled by letter and telephone. They were selected based on the predetermined values according to their previous measured waist circumference and age available from the MONICA 4 database. A maximum of 1800 subjects were available for recruitment. The response rate was about 50%. From these, quota sampling was used in order to assign approximately equal number in each subgroup aiming for 50 men and 50 women in each of 12 subgroups defined by sex, waist circumference Action Levels (below Action Level 1, between Action Level 1 and Action Level 2, and above Action Level 2), and age (below and above 50 years) . Subjects were randomised within each subgroup. One group received general advice about weight management and were given the 'Waist Watcher' tape measure with which to monitor their waist circumference and guidance in its use. The other group, serving as controls, did not receive advice or the tape measure. In the present study, baseline self-reported, self-measured and self-classified waist circumference according to the Action Levels were compared to those made by the investigator, in 94 men and 45 women who were available at the time of analyses.

Anthropometry

Reported measurements

Subjects were asked to complete a postal questionnaire about current body weight, height, waist and hips at home. Additional data to be analysed later includes information on subjects' selection of body shapes based on silhouette photographs of men and women with a wide range of body fatness and fat distribution, history of weight management, lifestyle habits, family and medical history. Subjects will be recalled to measure waist circumference and body weight after six months to assess the effectiveness of the 'Waist Watcher' tape measure in self-weight management, compared to the control group. Long term monitoring of weight management is planned.

Self-measurement using the 'Waist Watcher' tape measure

The 'Waist Watcher' tape measure (**Figure 10.1.1**) was made to help subjects measure their waist circumference easily. The tape can be made into a complete loop and fitted firmly around the waist by a spring mechanism, controlled by a push-button. This allows subjects with free hands for adjusting the tape. The measurement can be conveniently read by removing the tape from the waist, which is particularly helpful to overweight subjects who find it hard to read bending down. The tape has the conventional numbers in centimetres and inches on each side, and three colour bands separated by Action Levels: **green band** to indicate waist below Action Level 1 (<94 cm in men, <80 cm in women); **amber band** between 'Action Level 1 and 'Action Level 2; (94-102 cm in men, 80-88 cm in women); and **red band** above Action Level 2 (≥102 cm in men, ≥88 cm in women). The meaning of the band colours are explained in the handout '*Recommendations for Weight Management*', which includes a set of step-by-step photographic instructions to guide subjects how to measure their waist circumference without any assistance from the investigator (**Figure 10.1.2**).

Waist circumference measured by investigator

At the end of the experiments, subjects were asked to be measured by the investigator, thus subjects would not know beforehand that their measurement of the waist would be checked. Also, the investigator did not see the subjects' measurement values.

Analysis

The accuracy of self-reported waist circumference, self-measured and self-classification of waist circumference into categories according to the Action Levels using the 'Waist Watcher', were compared to those made by the investigator, which were considered as the reference method. Statistical and graphical presentation based on the Bland and Altman (1986) methods were used to characterise the bias, errors and limits of agreement of measurements in relation to sex, waist size and age. The proportions of subjects classified into categories of waist circumference Action Levels based on their waist circumference measured by the investigator were used as reference groups for large waist, above Action Level 1 (≥94 cm in men, ≥80 cm in women) or above Action Level 2 (≥102 cm in, and ≥88 cm in women). Sensitivities and specificities (Bland, 1987) were calculated to assess subjects' ability to classify themselves correctly into categories according to waist circumference Action Level 1 or Action Level 2.

RESULTS

Table 10.1.1 shows the subjects' characteristics. The mean values of self-reported measurements and those made by the trained investigator were similar. Nearly all subjects reported all the measurements, except only 36% men were able to provide their hip measurement.

Waist circumference measurements made by the investigator were used as the reference values. The errors of self-reported home-assessed waist circumference from subjects (self-reported minus reference) were -7.1 cm (95% confidence interval: -21.5 to 6.5) in men and -5.2 cm (95% confidence interval: 22.2 to 11.9) in women (**Table 10.1.1, Figures 10.1.3a & b**). There was a systematic bias in errors of self-reported waist in men (r = -0.63, P <0.001) and in women (r = -0.48, P <0.001) of different waist size (**Figures 10.1.3a & b**), i.e. subjects with smaller waist tended to overestimate and those with a larger waist to underestimate their waist size, compared to the reference values.

The errors of waist circumference measured by subjects using the 'Waist Watcher' tape measure (self-measured minus reference) were -0.6 cm (95% confidence interval: -6.5 to 5.4) in men and -0.6 cm (95% confidence interval: -5.3 to 4.5) in women (**Table 10.1.1, Figures 10.1.4a & b**). There was a systematic bias in errors of self-measured waist circumference (r = -0.36, P = 0.01) in men of different waist size (**Figure 10.1.4a**), i.e. men with smaller waist tended to obtain higher and those with larger waist tended to obtain lower waist measurements, compared to the reference values. No bias in the errors of self-measured waist circumference was observed (r = 0.02, P = 0.88) in women of different waist size (**Figure 10.1.4b**). The variability (spread) in the errors of self-measured waist circumference was similar throughout the range of waist circumference, i.e. subjects with larger waist gave the same limits of errors as those with smaller waist (**Figures 10.1.4a & b**).

There were no significant systematic biases in the errors of self-reported waist with age in men (r = 0.19, P = 0.6) and in women (r = -0.23, P = 0.07) (**Figures 10.1.5a & b**), or in the errors of self-measured waist with age in men (r = 0.11, P = 0.26) and in women (r = -0.01, P = 0.92) (**Figures 10.1.6a & b**). In younger men and younger women below 40 years (**Figures 10.1.6a & b**), the variability (spread) of errors of self-measured waist circumference was less than in the older groups.

Table 10.1.2 shows that the proportions of subjects in each categories of waist circumference Action Levels were roughly equal (35%) using reference measurement made by investigator. This was expected as quota sampling was employed to ensure approximately equal numbers of subjects in each category were recruited, based on their waist circumference measured one year previously. Subjects tended to underreport their waist, such that there were fewer numbers in the lowest (below Action Level 1) waist category based on self-reported waist measurement. The distribution of subjects in each category based on waist circumference measured by subject using the 'Waist Watcher' was almost identical to the reference.

In **Table 10.1.3**, subjects in categories of waist Action Level 1 or Action Level 2 identified by the investigator were used as reference. Self-reported waist circumference of men and women, respectively, would be classified correctly in different categories based on Action Level 1 with sensitivities of 57.4% and 74.3%, and specificities of 92.5% and 100%, and Action Level 2 with sensitivities of 32.4% and 27.8%, and specificities of 98.5% and 93.2%. With the aid of the 'Waist Watcher' tape measure and photographic instructions, men and women, respectively, self-classified their waist circumference correctly according to Action Level 1 with sensitivities of 100% and 94.3%, and specificities of 95.0% and 96.3%, and according to Action Level 2 with sensitivities of 97.1% and 100%, and specificities of 100% (both sexes). There were less than 2% of subjects who misclassified themselves into the wrong categories of waist based on the Action Levels.

DISCUSSION

We have addressed the public health needs, using a single measurement of waist circumference to alert the general public to their risks of ill health, and their need to seek professional help based on the Action Levels of waist circumference (**Chapter 4.1**; Lean *et al*, 1995). Both men and women underreported their waist circumference, thus the specificities for classification of subjects into the lower categories of waist Action Levels were high (>93%), but the sensitivities for identifying those with larger waist in higher categories of waist Action Levels were very low - 57-74% based on Action Level 1 and about 30% based on Action Level 2. With the aid of the 'Waist Watcher' tape measure (**Figure 10.1.1**) and photographic instructions (**Figure 10.1.2**) which were designed specifically for the present study, to help subjects measure their waist easily, most subjects could identify themselves correctly in different categories of waist circumference according to the Action Levels with sensitivities and specificities above 94%, thus the 'Waist Watcher' tape measure provides a useful screening tool, in health promotion, for self-classification of increased health risk through intra-abdominal fat accumulation, otherwise would be missed from self-reported waist circumference.

Our previous findings indicate clearly that large waist circumference is associated with symptoms of obesity and secondary diseases (**Chapter 5**) imposing enormous burdens of ill health on health services and society (**Chapter 6**). Waist circumference as an index of adiposity is minimally influenced by height (**Chapter 4.3**; Han *et al*, 1997c), although height does have an influence on health independent of adiposity. Thus, a single measurement of waist circumference is a valid and simple indicator of ill health. If waist circumference is to be used for health promotion programmes for weight management in the general public, it is essential that the subjects should be able to measure their waist correctly. Some previous studies have shown waist circumference measured by trained observers is reliable (Rimm *et al*, 1990; Hall and Young, 1989, Ferrerio, 1995), but recent study on self-reported weight and height in British teenagers (16-17 years) found that shorter and fatter individuals overestimated their height and underestimated their weight, while conversely taller and thinner subjects underestimated their height (Crawley and Portides, 1995). The agreement between self-reported and self-measured values for height and weight were within 1 cm and 1 kg respectively, but they varied (95% confidence interval) by 7 cm and 7 kg respectively (Nakatsuka *et al*, 1995). In these studies, conventional tape measures were used, and these may be problematic for the very obese who cannot see their waist. The 'Waist Watcher' allows a more reliable 'blind' measurement. The present study found that the variability of errors (spread of errors about the mean error) of self-measured waist circumference was similar in subjects of different of waist size (**Figures 10.1.4a & b**), and younger people were able to measure their waist more accurately than older groups (**Figures 10.1.6a & b**). In the present study, while nearly all subjects were able to report all home-assessed measurements, only 36% men offered hip circumference measurement. These results provide further support for the use of a single measurement of waist circumference in health promotion directed at general public.

The present study is part of a larger prospective study. At baseline, waist size self-reported and self-measured by the subjects using the 'Waist Watcher' tape measure were compared to that measured by the investigator. Subjects will be recalled in six months to assess the effectiveness of the 'Waist Watcher' tape, used as a motivational tool to prevent weight gain in those with waist below Action Level 1, and to encourage weight loss in those with waist above Action Level 1. In addition, comparisons between weight and height measured by the investigator and those reported by the subjects, and the influences of body image perception on the differences between self-reported or self-measured anthropometry and assessment by an investigator will be evaluated.

The practical value of this research is that a single measurement of waist circumference can be adopted confidently both by health professionals and the general public as a tool for alerting individuals who need weight management. Health promotion can contribute to weight management by alerting people to their level of risk and the need to take action. This implies the need to establish specialised obesity clinics to serve these needs. Individuals with waist circumference below Action Level 1 do not need to lose weight but should be aware of potential health risks if their waist exceeds this level. In the range between Action Level 1 and Action Level 2, people should not further gain weight, with lifestyle modification such as increasing physical activity level and some self-weight management. Everybody above Action Level 2, should be urged to take action and to seek professional help to achieve sustained weight loss. These waist Action Levels have already been recognised by epidemiologists in the field of public health (Carey *et al*, 1997), and adopted for national health promotion by British Diabetic Association

(Walker, 1997), Health Education Board for Scotland (1997), and Scottish Intercollegiate Guidelines Network (1996). Loss of 5-10 cm in circumferentially challenged individuals is a goal warrants major congratulations (**Chapter 7**; Han *et al*, 1997a), and will help health service planners to rest easy!

CONCLUSIONS

A 'Waist Watcher' tape measure with photographic instructions offers advantages over self-reported measurement of waist in self-classifying waist size, and provides a useful tool for screening people at increased health risk through intra-abdominal fat accumulation.

Table 10.1.1. Characteristics of subjects.

	Men				Women			
	n	Mean	SD	Range	*n*	Mean	SD	Range
				Reported, home-assessed measurements				
Age (years)	101	51.4	10.3	27.9-66.6	62	49.2	10.1	28.6-67.1
Weight (kg)	101	83.7	15.1	57.2-120.8	62	70.0	12.8	50.8-101.7
Height (cm)	101	172.7	7.4	158.0-190.0	62	159.5	5.8	148.0-173.0
BMI (kg/m^2)	101	28.4	4.5	19.8-39.7	62	27.6	5.5	18.9-45.2
Waist (cm)	100	91.8	9.7	71.1-119.4	62	78.9	10.8	58.4-111.8
Hips (cm)	36	97.9	13.1	81.3-137.2	61	100.9	10.0	76.2-127.0
				Waist circumference by subjects using 'Waist Watcher' *tape measure*				
Waist (cm)	101	98.2	11.9	73.0-130.0	62	83.3	11.7	65.0-113.0
				Measurements by investigator				
Weight (kg)	101	84.3	15.8	53.9-126.6	62	71.1	12.8	51.5-103.5
Height (cm)	101	173.7	7.4	157.9-191.4	62	161.0	5.6	146.8-172.2
BMI (kg/m^2)	101	27.9	4.47	18.4-40.9	62	27.5	5.5	19.5-44.9
Waist (cm)	101	98.7	12.7	71.2-129.3	62	83.8	11.4	65.7-114.5
Hips (cm)	101	104.8	7.8	89.0-130.0	62	105.1	9.4	87.0-137.2
Waist to hip ratio	101	0.94	0.07	0.79-1.13	62	0.80	0.06	0.68-0.90
				Errors of self-reported and self-measured waist circumference (cm)				
				95% CI†				95% CI†
SR-reference	100	-7.14	7.18	-21.50, 6.47	62	-5.16	8.53	-22.2, 11.90
SM-reference	101	-0.55	2.99	-6.53, 5.43	62	-0.56	2.36	-5.28, 4.46

†95% confidence interval limits of agreement (±2 SD of the mean error); SR-reference = self-reported waist circumference minus reference values measured by investigator; SM-reference = self-measured waist circumference using 'Waist Watcher' minus reference values measured by investigator.

Table 10.1.2. Proportions of subjects in different categories of waist circumference Action Levels identified from measurements made by investigator (reference), from self-reported, and from subjects self-measurements using the 'Waist Watcher' tape measure.

	By investigator (reference)		Self-reported		Self-measured	
Waist circumference (cm)	*n*	%	*n*	%	*n*	%
Men ($n = 101$)						
<94	40	39.6	63	62.4	38	37.6
94-102	27	26.7	26	25.7	30	29.7
≥102	34	33.7	12	11.9	33	32.7
Women ($n = 62$)						
<80	27	43.5	36	58.1	28	45.2
80-88	17	27.4	18	29.0	16	25.8
≥88	18	29.0	8	12.9	18	29.0

Table 10.1.3. Sensitivities and specificities of the identification of subjects into different waist circumference Action Level categories based on their reported and self-measured waist circumference, using groups classified from measurements made by the investigator as reference.

	Self-reported†		Self-measured‡	
	Sensitivity (%)	Specificity (%)	Sensitivity (%)	Specificity (%)
Men (n = 101)				
Action Level 1 (94 cm)	57.4	92.5	100	95.0
Action Level 2 (102 cm)	32.4	98.5	97.1	100
Women (n = 62)				
Action Level 1 (80 cm)	74.3	100	94.3	96.3
Action Level 2 (88 cm)	27.8	93.2	100	100

†Waist circumference was reported by subjects from home-assessment; ‡self-classification into waist circumference categories by subjects was aided by 'Waist Watcher' tape measure which has three band colours separated by Action Levels (**Figure 10.1.2**).

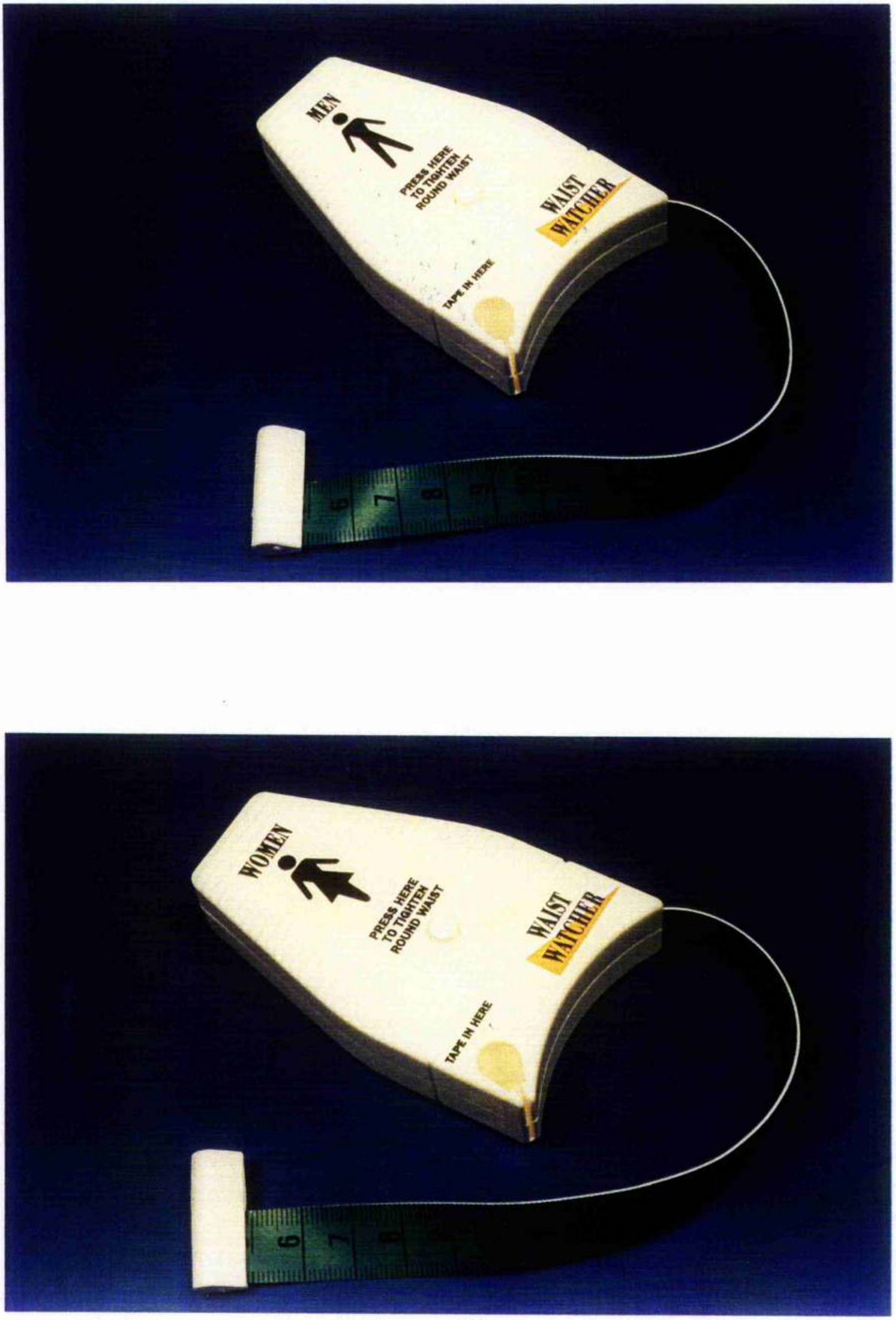


Figure 10.1.1. The 'Waist Watcher' tape measure.

Figure 10.1.2. Photographic instructions for self measurement of waist circumference using the 'Waist Watcher' tape measure. The booklet also contains recommendations of dietary intake and physical activity for weight management, adopted from the Health Education Board for Scotland (HEBS).

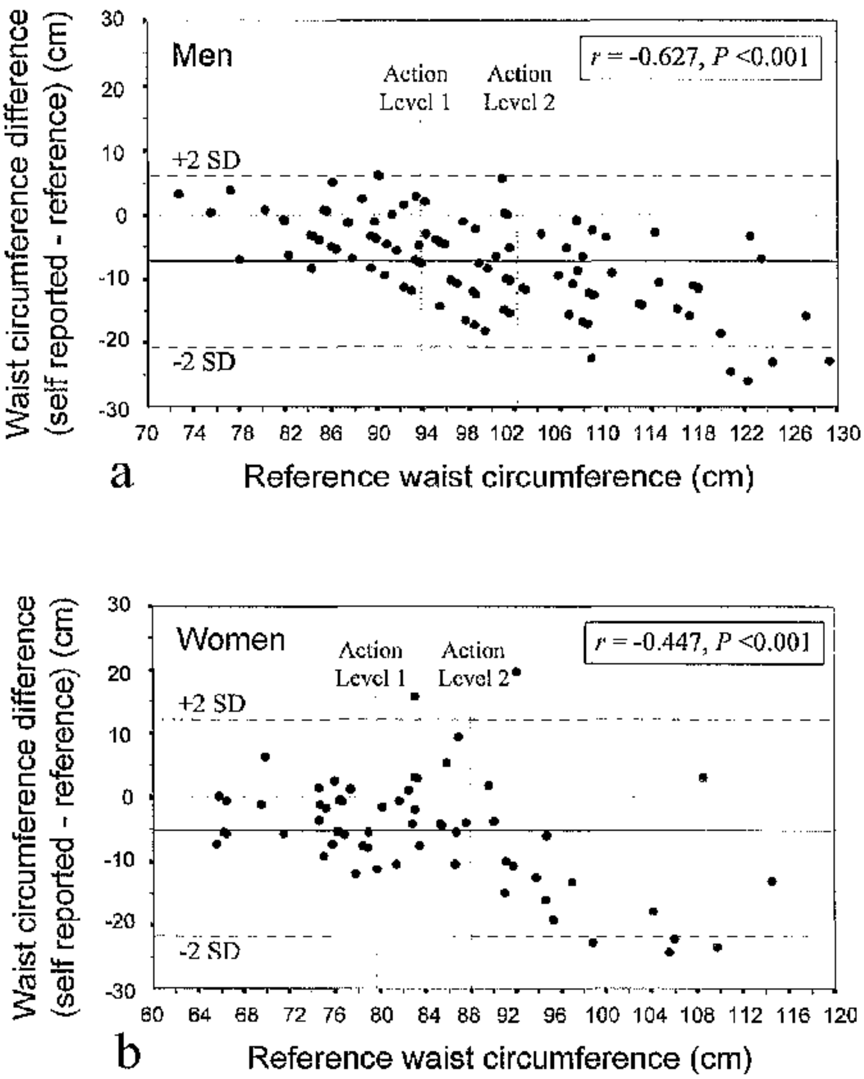
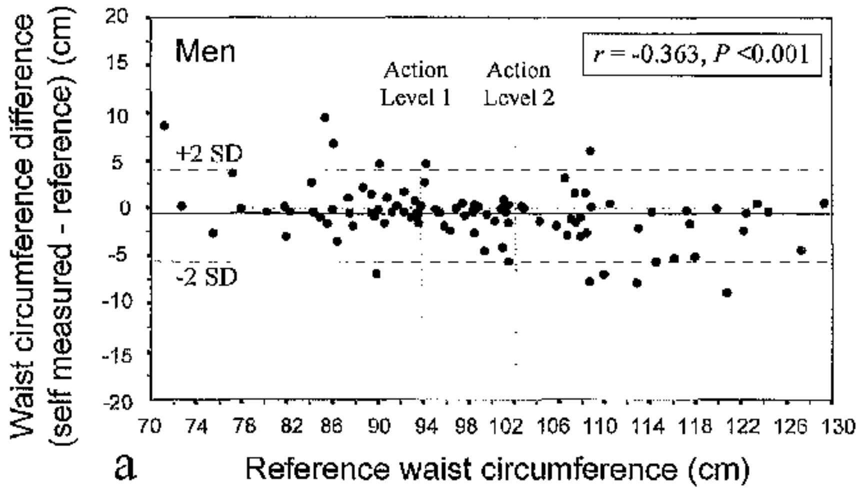


Figure 10.1.3. Plots of errors of self-reported waist circumference (subjects' self-reported values minus reference values measured by investigator) against reference values, in 101 men (a) and 62 women (b). Solid line indicates mean error, and dashed lines indicate 95% confidence interval limits of agreement (±2 SD of the mean error).



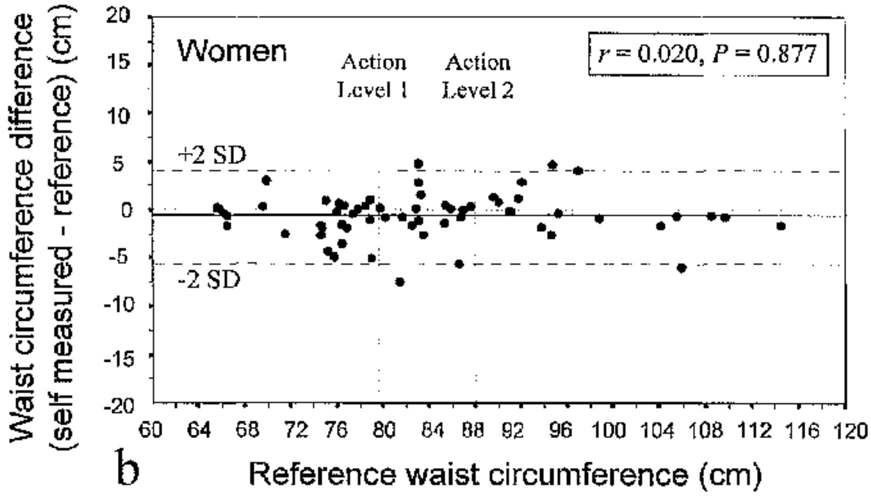


Figure 10.1.4. Plots of errors of self-measured waist circumference using 'Waist Watcher' tape measure (subjects' self-measured values minus reference values measured by investigator) against reference values, in 101 men (a) and 62 women (b). Solid line indicates mean error, and dashed lines indicate 95% confidence interval limits of agreement (±2 SD of the mean error).

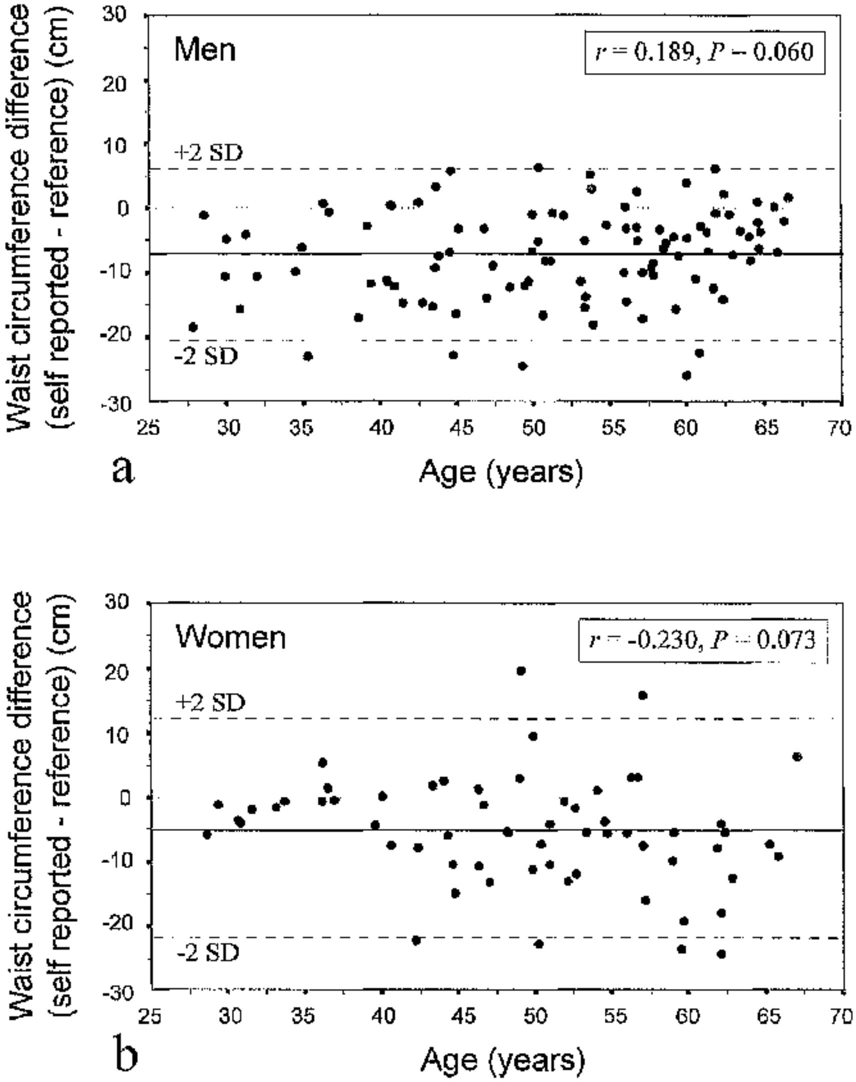


Figure 10.1.5. Plots of errors of self-reported waist circumference (subjects' self-reported values minus reference values measured by investigator) against subjects' age, in 101 men (a) and 62 women (b). Solid line indicates mean error, and dashed lines indicate 95% confidence interval limits of agreement (±2 SD of the mean error).

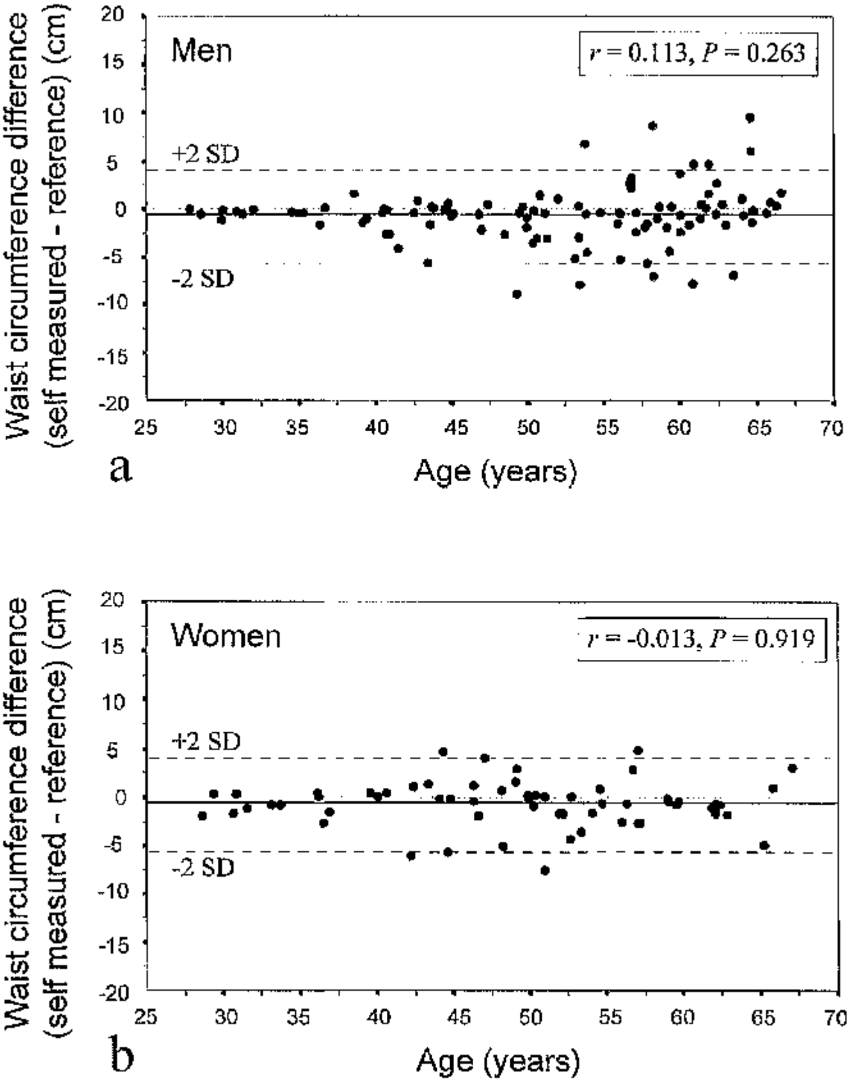


Figure 10.1.6. Plots of errors of self-measured waist circumference using 'Waist Watcher' tape measure (subjects' self-measured values by minus reference values measured by investigator) against subjects' age, in 101 men (a) and 62 women (b). Solid line indicates mean error, and dashed lines indicate 95% confidence interval limits of agreement (±2 SD of the mean error).

CHAPTER ELEVEN

GENERAL DISCUSSION OF THE FINDINGS AND CONCLUSIONS OF THE PRESENT THESIS

	CONTENTS OF CHAPTER ELEVEN	PAGES

11.1 Overall conclusions of the findings and answers to research questions

11.1.1 Development of simple anthropometric methods for assessing body morphology

Recognising the limited success in preventing the rising prevalence of overweight in Western countries, the studies in the present thesis have focused on the development and validation of a simple method for assessing adiposity. Several approaches were taken to re-examine, develop and validate a wide range of methods to determine adiposity. The research question "*Are existing methods of measuring body morphology satisfactory in terms of accuracy and practicality*?" was answered in **Chapter 3.1**. It was shown that conventional skinfold method are not entirely satisfactory because it underestimated body fat in extreme central fatness and older age. Waist circumference method showed no bias in these groups. The advantages of the waist circumference method are the convenience and ease of measurement. The equations employing waist circumference were found to be robust in cross-validation with a Dutch sample. Research question "*Can a better novel method be derived to reflect central fat and total adiposity*?" was posed. In **Chapter 4.1**, it is argued that the waist circumference is better by virtue of practicality, and also its better reflection of both total fat and central (intra-abdominal) fat. Further more, ROC analysis has shown that waist circumference 'Action Level 1' coincided with the 'optimal' cut-offs, where sensitivity equals specificity for identifying major cardiovascular risk factors.

11.1.2 Relationships between body morphology and metabolic disorders

It is now well accepted that excessive intra-abdominal fat accumulation is a health hazard, and that waist circumference reflects this fat mass. To answer the research question "*How well does waist circumference relate to metabolic disorders compared to the existing methods of body mass index and waist to hip ratio*?", A series of cross-sectional epidemiological studies in **Chapter 5** showed that waist circumference related at least as well as other commonly used anthropometric indices of body mass index and waist to hip ratio, to a cluster of symptoms and chronic diseases including cardiovascular risk factors, respiratory insufficiency, diabetes mellitus, symptoms of low back pain and impairment of quality of life. Analyses in chapter 4 show that there is no need to adjust waist circumference for height.

11.1.3 Some determinants of body morphology and metabolic disorders

Animal studies have shown imbalance diet during early growth can affect skeletal structure. The research question "*Does disproportionate stature (limb lengths relative to height) associate with health hazards*?" was answered in a study of body lengths in **Chapter 8**. Men and women with body disproportions appeared to relate to specific metabolic disorders. This was a relatively small study in relation to the prevalence of disease, so the apparent difference between men and women should ideally be confirmed in larger samples.

Several studies have indicated that increased proportions of type 2b muscle fibres are associated with features related to metabolic syndrome X. It has previously been established that athletes who are specialised in power sports tend to have higher proportions of type 2b muscle fibres, as opposed to type 1 muscle fibre predominance in athletes who are specialised in endurance sports. The research questions "*Is the musculoskeletal system affected by low birth weight, contributing to altered body functional capacity in adult life*? and "*Do individuals with declared natural ability in power sports suffer higher rate of coronary heart disease*?" were answered in a retrospective self reported study of former soldiers in **Chapter 9**. The data supported Barker et al, in showing a significant relationship between low birth weight and CHD. There was an indication that those who reported having a natural ability in power sports at the age between 16-40 to have increased risk of coronary heart disease and predisposing risk factors, compared to those who considered themselves as having a natural endurance sporting ability. There was no interaction between birth weight and sporting ability on metabolic disorders. Compared to men with a natural ability in endurance sports and above median birth weight, those with a natural ability in power sports and below median birth weight were more likely to develop cardiovascular disorders later in life.

11.1.4 Implications of altered body morphology on health risks applied towards health promotion

Waist circumference has been suggested as a simple method for assessing associated health risk, directed at the general public. Research questions posed in the present thesis "*Is self-reported waist circumference reliable*?" and "*Does a patent 'Waist Watcher' tape measure improve self-measurement*?" was answered by a study of reported home-based measurement and waist measurement using the 'Waist Watcher' tape measure. Results in **Chapter 10** showed that the error was reduced with the use of the 'Waist Watcher' and that more than 95% of subjects were able to self-classify themselves correctly into different categories according to the waist 'Action Levels'.

Conclusion

An attempt to synthesise the findings in this thesis, together with evidence collected by other, is made in **Figure 11.2.1**, as a progression from the simple model shown in **Figure 1.2.1**. Some of the new links are firmly established by evidence, others remain speculative.

11.2 Validity of conclusions, limitations of the studies in the present thesis, and future research directions

In this section, the validity of the conclusions and limitations of the studies in the present thesis, and future research direction are discussed. Possible mechanisms linking body morphology, early growth and metabolic complications will be formulated to postulate further hypotheses for future studies.

11.2.1 Validity and limitations of the studies and further research needs

The present thesis has drawn on a wide range of studies to explore the importance of body morphology in relation to metabolic disorders in adults. The associations of overweight and fat distribution with metabolic disorders were obtained mostly from cross-sectional studies. To be able to confirm aetiological relationship, a longitudinal follow up is necessary, and this is underway in the MORGEN study. The retrospective follow up study of natural sporting ability and coronary heart disease in later life used indirect markers and reported information rather than actual physical and biological measurements. Prospective studies using measured variables should be conducted to confirm the findings from this study. This study, and the analysis of limb length and disease are both limited by relatively small size in relation to the prevalences of diseases in the samples.

The present thesis has derived a number of anthropometric methods based on waist circumference measurement to identify body fatness. Measurements of waist circumference was highly reproducible. Derived predictive equations and standard cut-offs of waist circumference to define body mass index and waist to hip ratio were found to be robust in cross-validation on different populations. The same cut-off points were found using different methodological and analytical approaches, e.g. analysis of risk factors. Waist circufmerence, strongly reflects intra-abdominal, correlated consistently with a variety of symptoms and indices of ill health. Thus the methods employing waist circumference can be applied for assessing health risk associated with obesity and abdominal fat accumulation confidently by health professionals, and in health promotion directed at the general public.

11.2.2 Future research directions

Extensive research into the aetiology of overweight and body fat distribution as indicators of ill health and metabolic disorders has focused on genetic and environmental factors and their interactions. However, recent evidence emerged from the epidemiological studies of Barker and colleagues has pointed towards early malnutrition, reflected by poor growth, as a major determinant of the same metabolic diseases in adulthood, including cardiovascular disease, diabetes and lung disease. These authors' interpretations of the associations between increased risks of diseases in adults and their low weight at birth or at one year were based on the 'thrifty phenotype' hypothesis which suggests that growth and development of vital organs are sacrificed to sustain brain growth when unfavourable conditions occur (e.g. malnutrition). If this occurs during the critical period of early growth, the 'programming' hypothesis suggests vital organs may be permanently damaged: these functional defects can persist into adult life, rendering subjects greater susceptibility to ill health.

Does muscle fibre composition have a direct influence on metabolic diseases, or does it require the metabolism of the muscle fibres through different metabolic pathways to express the metabolic risks exerting on the cardiovascular system and other organs? Is it possible that failure in growth at a specific time of pregnancy and/or the severity of the insult determines the composition, and thus functional capacity of skeletal muscles? According to the 'thrifty phenotype' hypothesis used to explain the relationships between early growth and metabolic disorders, muscle morphology may also be affected by early growth. It would be expected that type 2 muscle fibres are more predominant in people who were malnourished (low birth weight) during intra-uterine development. In such adverse condition, blood may be diverted towards the brain at the expense of peripheral organs. This hypothesis is supported by several studies of blood distribution. Chronic hypoxia, produced by embolisation of the uteroplacental bed in fetal lamb, led to blood redistributed towards the brain (Reuss *et al*, 1982; Block *et al* 1984). Blood flow redistributed towards the brain has also been shown in asymmetrical, relatively larger head than waist circumference, growth retarded human foetuses (Al-Ghazali *et al*, 1989). Thus in such situation of peripheral blood (nutrient) deprivation, the skeletal muscles would probably adapt towards a metabolic system relying less on oxidative, i.e. more glycolytic, less vascularised type 2 muscle fibres. The morphology and function of the skeletal muscles would then be permanently 'programmed' for life, limiting subjects to rely on glycolytic metabolism, with a decreased ability to perform physical activities involving oxidative metabolism, whereas the ability to perform power activities which are not dependent on oxygen would probably not be impaired. Barker (1994) has proposed that early growth restraint, including undernutrition at different stages of pregnancy may result in disproportionate body size, accompanied by abnormal development of organs, reflected by altered organ size, morphology and function, and this may persist throughout an individual's life. It is possible that there may be many more hierarchical steps to sustain growth of more vital organs, i.e. the nervous system, vital organs and musculoskeletal system in that order. In the present study, we hypothesise that the musculoskeletal system may be one of the first body organs to be 'sacrificed'. This is in agreement findings from development of pigs reared on different diet composition and energy intake (McCance, 1968).

Emerging from the present thesis, several future research projects can be proposed.

1. Longitudinal studies of waist circumference and ill health.

2. Physiological measures of muscle function and metabolic status in different clinical situations.

3. Follow up study of the effectiveness of the 'Waist Watcher' tape measure in self weight management in free living subjects.

4. Long term intervention for primary prevention of obesity employing waist circumference in high risk individuals.

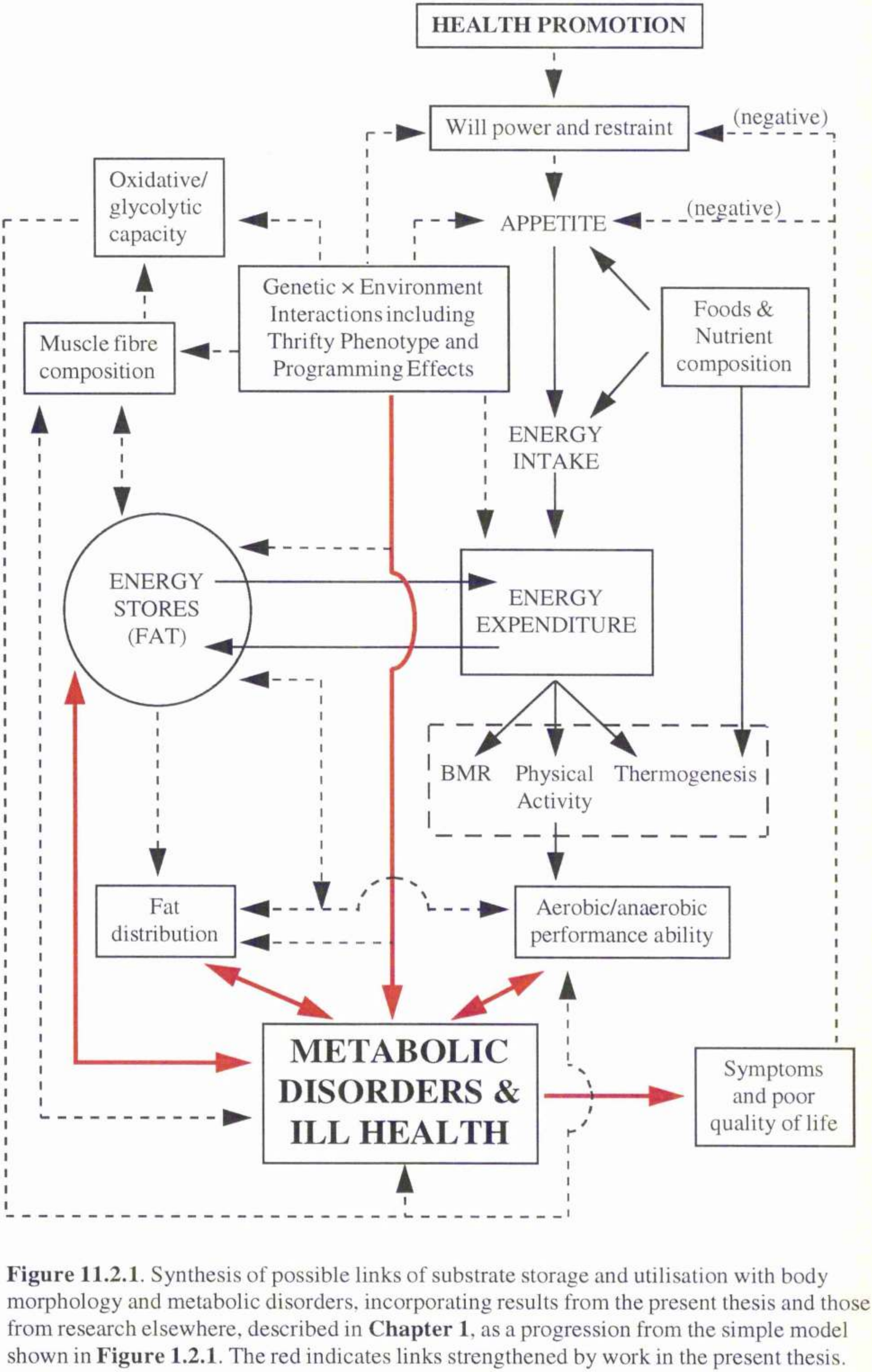


Figure 11.2.1. Synthesis of possible links of substrate storage and utilisation with body morphology and metabolic disorders, incorporating results from the present thesis and those from research elsewhere, described in **Chapter 1**, as a progression from the simple model shown in **Figure 1.2.1**. The red indicates links strengthened by work in the present thesis.

REFERENCES

1. Abate N, Burns D, Peshock RM, Garg A, Grundy SM. Estimation of adipose tissue by magnetic resonance imaging: validation against dissection in human cadavers. *J Lipid Res* 1994; **35:**1490-96.

2. Abate N, Garg A, Coleman R, Grundy SM, Peshock RM. Prediction of total abdominal, intraperitoneal, and retroperitoneal tissue masses in men by single axial magnetic resonance imaging slice. *Am J Clin Nutr* 1997; **65:**403-08.

3. Al Ghazali W, Chita SK, Chapman MG, and Allan LD. Evidence of redistribution of cardiac output in asymmetrical growth retardation. *Br J Obstet Gynaecol* 1989; **96:**697-704.

4. Allon N. Self-perceptions of the stigma of overweight in relationship to weight-losing patterns. *Am J Clin Nutr* 1979; **32:**470-80.

5. Alvarsson M, Efendic S, Grill VE. Insulin response to glucose in healthy males are associated with adult height but not with birth weight. *J Intern Med* 1994; **236:**275-79.

6. Andersen P, Henriksson J. Capillary supply of the quadriceps femoris muscle of man: adaptive response to exercise. *J Physiol (Lond)* 1977; **270:**677-90.

7. Andersen RE, Wadden TA, Bartlet SJ, Vogt RA, Weinstock RS. Relation of weight loss to changes in serum lipids and lipoproteins in obese women. *Am J Clin Nutr* 1995; **62:**350-57.

8. Andrés R, Elahi D, Tobin JD, Muller DC, Brant L. Impact of age on weight goals. *Ann Intern Med* 1995; **103:**1030-33.

9. Ashwell M, Cole TJ, Dixon AK. Obesity: new insight into the anthropometric classification of fat distribution shown by computed tomography. *Br Med J* 1985; **250:**1692-94.

10. Ashwell M, Cole T, Dixon A. Ratio of waist circumference to height is strong predictor of intra-abdominal fat. *Br Med J* 1996; **313:**559-60. [Lett].

11. Åstrand P-O, Rodahl K. *Textbook of work physiology. Physiological bases of exercise* (3rd edn). New York: McGraw-Hill, 1986.

12. Atkinson RL. Proposed standards for judging the success of the treatment of obesity. *Ann Intern Med* 1993; **119:**677-80.

13. Austin MA, King M-C, Vranigan KM, Krauss RM. Atherogenic lipoprotein phenotype: a proposed genetic marker for coronary heart disease. *Circulation* 1990; **82**:495-506.

14. Barata J, Schoen T, van Dijk T, Wilmore J. Comparison of two generalised skinfolds protocols for assessing fat mass in young adult population engaged in sport. *Int J Obes* 1993; **17(suppl 2):**16. [Abstr].

15. Barker DJP, Osmond C, Golding J. Height and mortality in the counties of England and Wales. *Ann Hum Biol* 1990; **17:**1-6.

16. Barker DJP. *Fetal and infants origins of adult disease*. London: BMJ Publishing Group, 1992.

17. Barker DJP. *Mother, babies, and disease in later life*. London: BMJ Publishing Group, 1994.

18. Bassey EJ. Demi-span as a measure of skeletal size. *Ann Hum Biol* 1986; **13:** 499-502.

19. Bedell G, Wilson W, Seebohm P. Pulmonary function in obese persons. *J Clin Invest* 1958; **37:**1049-60.

20. Bell RD, MacDougall JD, Billetter R, Howald H. Muscle fibre types and morphometric analysis of skeletal muscle in six-year-old children. *Med Sci Sports Exerc* 1980; **12:**28-31.

21. Belsley DA, Kuh E, Welsch RE. *Regression diagnostics: identifying influential data and sources of collinearity*. New York: Wiley & Sons, 1980.

22. Benn RT. Some mathematical properties of weight-for-height indices used as measures of adiposity. *Br J Prev Soc Med* 1971; **25:**42-50.

23. Bennett N, Dodd T, Flatley J, Freeth S, Bolling K. *Health survey for England 1993: a survey carried out by the social survey division of OPCS on behalf of the department of health*. London: HMSO, 1995.

24. Björntorp P. Adipose tissue in obesity (Willendorf Lecture). In: Hirsh J, Van Itallie T (eds). *Recent advances in obesity research IV*, pp163-70. London: John Libbey, 1985.

25. Björntorp P. Classification of obese patients and complications related to the distribution of surplus fat. *Am J Clin Nutr* 1987; **45 (suppl 5):**1120-25.

26. Björntorp P. Metabolic implications of body fat distribution. *Diabetes Care* 1991; **12:**1132-43.

27. Björntorp P. Biochemistry of obesity in relation to diabetes. In: Alberti KGMM, DeFronzo RA, Keen H, Zimmet P. *International textbook of diabetes mellitus*, pp551-68. London: John Wiley & Sons, 1992.

28. Björntorp P. The regulation of adipose tissue distribution in humans. *Int J Obes* 1996; **20:**291-302.

29. Blair SN. Evidence for success of exercise in weight loss and control. *Ann Intern Med* 1993; **119:**702-06.

30. Blair SN, Booth M, Gyarfas I, Iwane H, Marti B, Matsudo V *et al.* Development of public policy and physical activity initiatives internationally. *Sports Med* 1996a; **21:**157-63.

31. Blair SN, Horton E, Leon AS, Lee I-M, Drinkwater BL, Dishman RK *et al.* Physical activity, nutrition, and chronic disease. *Med Sci Sports Exerc* 1996b; **28:**335-49.

32. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986; **i:**307-10.

33. Bland M. *An introduction to medical statistics*. Oxford: Oxford University Press, 1987.

34. Block BS, Llanos AJ, Creasy RK. Responses of the growth-retarded fetus to acute hypoxemia. *Am J Obstet Gynecol* 1984; **148:**878-85.

35. Boddy K, King PC, Hume R, Weyers E. The relation of total body potassium to heights, weights, and age in normal adults. *J Clin Pathol* 1972; **25:**512-17.

36. Bolinder J, Kager L, Ostman J, Arner T. Differences at the receptor and post receptor levels between human omental and subcutaneous adipose tissue in the action insulin lipolysis. *Diabetes* 1883; **32:**117-23.

37. Bonen A, Tan MH, Watson-Wright WM. Insulin binding and glucose uptake in rodent skeletal muscle. *Diabetes* 1981; **30:**702-04.

38. Bouchard C, Savard R, Després JP, Tremblay A, Leblanc C. Body composition in adopted and biological siblings. *Hum Biol* 1985; **67:**61-75.

39. Bouchard C, Pérusse L, Leblanc C, Tremblay A, Thériault G. Inheritance of the amount and distribution of human body fat. *Int J Obes* 1988; **12:**205-15.

40. Bouchard C, Tremblay A, Després J-P, Nadeau A, Lupien PJ, Thériault G *et al.* The response to long-term overfeeding in identical twins. *N Engl J Med* 1990; **322:**1477-82.

41. Bouchard C, Shephard RJ, Stephens T (eds). *International proceedings and consensus statement. Physical activity, fitness, and health.* Champaign, Il: Human Kinetics Publishers, 1994.

42. Boyd-Orr J. Milk consumption and the growth of school children. *Lancet* 1928; **i:**202-03.

43. Brennan GP, Ruhling RO, Shultz BB, Johnson SC, Andrews BC. Physical characteristics of patients with herniated intervertebral lumbar discs. *Spine* 1987; **12:**699-702.

44. Brodie DA. Techniques of measuring body composition. Part I. *Sports Medicine* 1980; **5:**11-40.

45. Brooke MH, Kaiser KK. Muscle fibre types: how many and what kind? *Arch Neurol* 1970; **23:**369-79.

46. Brown DC, Byrne CD, Clark PM, Cox BD, Day NE, Hales CN. Height and glucose tolerance in adult subjects. *Diabetologia* 1991; **34:**531-33.

47. Buller AJ, Eccles JC, Eccles RM. Interactions between motorneurons and muscles in respect to the characteristic speed of their responses. *J Physiol (Lond)* 1960; **150:**417-39.

48. Burney PGJ, Luczynska C, Chinn S, Jarvis D. The European community respiratory health survey. *Eur Respir J* 1994; **1:**954-60.

49. Carey DG, Jenkins AB, Campbell LV, Freund J, Chisholm DJ. Abdominal fat and insulin resistance in normal and overweight women. *Diabetes* 1996; **45:**633-68.

50. Carey VJ, Walters EE, Colditz GA, Solomon CG, Willett WC, Rosner BA, Speizer FE, Manson JE. Body fat distribution and risk of non-insulin-dependent diabetes mellitus in women. The nurses' health study. *Am J Epidemiol* 1997; **145:**614-19.

51. Carr-Hill RA, Rice N, Roland M. Socioeconomic determinants of rates of consultation in general practice based on fourth national morbidity survey of general practices. *Br Med J* 1996; **312:**1008-13.

52. Cardiovascular Review Group Committee on Medical Aspects of Food. *Nutritional aspects of cardiovascular disease: report of food policy*. London: HMSO, 1994.

53. Casimirri F, Pasquali R, Cesari MP, Melchionda N, Babara L. Interrelationships between body weight, body fat distribution and insulin in obese women before and after hypocaloric feeding and weight loss. *Ann Nutr Metab* 1989; **33:**79-87.

54. Chan JM, Rimm EB, Colditz GA, Stampfer MJ, Willett WC. Obesity, fat distribution, and weight gain as risk factors for clinical diabetes in men. *Diabetes Care* 1994; **17:**961-69.

55. Chowdhury B, Lantz H, Sjöström L. Computed tomography-determined body composition in relation to cardiovascular risk factors in Indian and matched Swedish males. *Metabolism* 1996; **45:**634-44.

56. Chumlea WC, Roche AF, Steinbaugh, ML. Estimating stature from knee height for persons 60 to 90 years of age. *J Am Geriatr Soc* 1985; **33:** 116-20.

57. Colditz GA. Economy costs of obesity. *Am J Clin Nutr* 1992; **55:**503S-07S.

58. Colditz GA, Giovannucci E, Rimm EB, Stampfer MJ, Rosner B, Speizer FE *et al.* Alcohol intake in relation to diet and obesity in women and men. *Am J Clin Nutr* 1991; **54:**49-55.

59. Colditz GA, Willett WC, Rotnitzky A, Manson JE. Weight gain as a risk factor for clinical diabetes in women. *Ann Intern Med* 1995; **122:**481-86.

60. Colman E, Katzel LI, Rogus E, Coon P, Muller D, Goldberg AP. Weight loss reduces abdominal fat and improves insulin action in middle-aged and older men

with impaired glucose tolerance. *Metabolism: Clinical and Experimental* 1995; **44:**1502-8.

61. Crawley HF, Portides G. Self-reported versus measured height, weight and body mass index amongst 16-17 year old British teenagers. *Int J Obes* 1995; **19:**579-84.

62. Croft PR, Rigby AS. Socioeconomic influences on back problem in the community in Britain. *J Epidemiol Comm Health* 1994; **48:**166-70.

63. Dattilo AM, Kris-Etherton PM. Effects of weight reduction on blood lipids and lipoproteins: a meta-analysis. *Am J Clin Nutr* 1992; **56:**320-28.

64. Davey-Smith G, Song F, Sheldon TA. Cholesterol lowering and mortality: the importance of considering initial level of risk. *Br Med J* 1993; **306:**1367-73.

65. DeFronzo RA. The triumvirate: β-cell, muscle, liver. A collusion responsible for Type 2 diabetes. *Diabetes* 1988; **37:**667-87.

66. Dempsey JA, Reddan W, Balke B, Rankin J. Work capacity determinants and physiologic cost of weight supported breathing in obesity. *J Appl Physiol* 1966; **21:**1815-20.

67. Den Besten C, Vansant G, Weststrate JA, Deurenberg P. Resting metabolic rate and diet induced thermogenesis in abdominal and gluteal femoral obese women before and after weight reduction. *Am J Clin Nutr* 1988; **47:**840-47.

68. Dennis KE, Goldberg AP. Differential effects of body fatness and body fat distribution on risk factors for cardiovascular disease in women. *Arterioscler Thromb* 1993; **13:**1487-94.

69. Den Tonkelaar I, Seidell JC, van Noord PAH, Baanders-van Halerwijn EA, Ouwehand IJ. Fat distribution in relation to age, degree of obesity, smoking habits, parity and estrogen use: a cross sectional study in 11 825 Dutch women participating in the DOM-project. *Int J Obes* 1990; **14:**753-61.

70. Den Tonkelaar I, Seidell JC, Collette HJA. Body fat distribution in relation to breast cancer in women participating in the DOM-project. *Breast Cancer Res Treat* 1995; **34:**55-61.

71. Dequeker JV, Baeyens JP, Caessens J. The significance of stature as a clinical measurement of ageing. *J Am Geriatr Soc* 1969; **17:** 169-79.

72. Després J-P, Moorjani S, Lupien PJ, Tremblay A, Nadeau A, Bouchard C. Regional distribution of body fat, plasma lipoproteins, and cardiovascular disease. *Arteriosclerosis* 1990; **10:**497-511.

73. Deurenberg P, Weststrate JA, van der Kooy K. Is an adaptation of Siri's formula for the calculation of body fat percentage from body density in the elderly necessary? *Eur J Clin Nutr* 1989; **43:**559-67.

74. Deurenberg P, Weststrate JA, Seidell JC. Body mass index as a measure of body fatness age- and sex- specific prediction formulas. *Br J Nutr* 1991; **65:**105-14.

75. Devlin JT. Effects of exercise on insulin sensitivity in humans. *Diabetes Care* 1992; **15 (suppl 4):** 1690-93.

76. Deyo RA, Bass JE. Lifestyle and low-back pain: the influence of smoking and obesity. *Spine* 1989; **14:**501-06.

77. Dirix A, Knuttgen HG, Tittel K (eds). *The Encyclopaedia of Sports Medicine: The Olympic Book of Sports Medicine*. Oxford: Blackwell Scientific Publications, 1991.

78. Donahoe M, Rogers RM, Wildon DO, Pennock BE. Oxygen consumption of the respiratory muscles in normal and in malnourished patients with chronic obstructive pulmonary disease. *Am Rev Respir Dis* 1989; **140:**385-91.

79. Dunn G. *Design and analysis of reliability studies: the statistical evaluation of measurement errors*. New York: Oxford University Press, 1989.

80. Durnin JVGA, Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women from 16 to 72 years. *Br J Nutr* 1974; **32:**77-97.

81. Edwards KL, Austin MA, Newman B, Mayer A, Krauss RM, Selby JV. Multivariate analysis of insulin resistance syndrome in women. *Arterioscler Thromb* 1994; **14:**1940-45.

82. Egger G, O'Neill M, Bolton A, Freeman D. Results of an abdominal obesity reduction program for men only: the gutbuster 'waist' loss program. *Int J Obes* 1995; **19 (suppl 2):**37. [Abstr].

83. Eklund JAE, Corlett EN. Shrinkage as a measure of the effect of load on the spine. *Spine* 1984; **9:**189-94.

84. Eisenburg BR. Quantitative ultrastructure of mammalian skeletal muscle. In: *Hand book of physiology: skeletal muscle*, pp73-111. Peachey LD, Adrian RH, Geiger SR (eds). Baltimore, MD: Williams and Willkins, 1983.

85. Eley S, Anderson AS, Lean MEJ, Paisley CM, Sparks P, Shepherd R. Constraints on dietary choice: the experience of an involuntary decrease in household income. In: Köhler BM, Feichtinger E, Barlösius E, Dowler E (eds). *Poverty and food in welfare societies,* pp186-95. Berlin: Edition Sigma, 1997.

86. Eriksson KF, Saltin B, Lindgärde. Increased skeletal muscle capillary density precedes diabetes development in men with impaired glucose intolerance. *Diabetes* 1994; **43:**805-08.

87. European Atherosclerosis Society. Strategies for the prevention of coronary heart disease: a policy statement of the European Atherosclerosis Society. *Eur Heart J* 1987; **8:**77-88.

88. Eveleth PB, Tanner JM. *Worldwide variation in human growth.* Cambridge: Cambridge University Press, 1976.

89. FAO/WHO/UNU. *Energy and protein requirements. Report of a joint FAO/WHO/UNU expert consultation.* Geneva, WHO: WHO technical report series 724, 1985.

90. Farebrother M, McHardy G, Munroe J. Relation between pulmonary gas exchange and closing volume before and after substantial weight loss in obese subjects. *Br Med J* 1974; **3:**391-93.

91. Ferrerio M, Carpenter MA, Chambless LE. Reliability of body fat distribution measurements. The ARIC study baseline cohort results. *Int J Obes* 1995; **19:**449-57.

92. Filley GF, Beckwitt HJ, Reeves JT, Mitchell RS. Chronic obstructive bronchopulmonary disease: II. Oxygen transport in two clinical types. *Am J Med* 1968; **44**:26-38.

93. Fischbach GD, Robbins N. Changes in contractile properties of disused soleus muscles. *J Physiol* (*Lond*) 1969; **201**:305-20.

94. Fisher RA, Yates F. *Statistical tables for biological, agricultural and medical research. Table XXXIII.* London: Longman Group, 1974.

95. Flodmark CE, Sveger T, Nilsso-Ehle P. Waist measurement correlates to a potential atherogenic lipoprotein profile in obese 12-14 year-old children. *Acta Paediatr* 1994; **83**:941-5.

96. Floud R, Wachter K, Gregory A. *Height, health and history: nutritional status in the United Kingdom, 1750-1980.* Cambridge: Cambridge University Press, 1990.

97. Fogel RW. *Long-term changes in nutrition and the standard of living.* Proceedings of Section B7. Ninth International Economic History Congress. Bern, 1986.

98. Fogel RW, Pope CL, Scrimshaw N, Temin P, Wimmer LT. The aging of Union Army men: a longitudinal study. *Mimeo*: Center for Population Economics. University of Chicago, 1986.

99. Fontvieille AM, Kriska A, Ravussin E. Decreased physical activity in Pima Indian compared with Caucasian children. *Int J Obes* 1993; **17**:445-52.

100. Fox EL, Bowers RW. Ross ML. *The physiological basis of physical education and athletics* (4th edn). Dubuque, Iowa: Wm C Brown Publishers, 1988.

101. Friedewald WT, Levy RI, Fredrickson DS. Estimation of the concentration of low density lipoprotein cholesterol in plasma without the use of preparative ultracentrafugation. *Clin Chem* 1972; **18:**499-502.

102. Garn SM, Clark DC. Trends in fatness and the origins of obesity. *Pediatrics* 1976; **57:**433-56.

103. Garrow JS. *Energy and obesity in man.* New York: Elsevier, 1974.

104. Garrow JS. *Treat obesity seriously: a clinical manual.* London: Churchill Livingston, 1981.

105. Garrow JS. Indices of adiposity. *Nutritional Abstract Reviews: Reviews in Clinical Nutrition* 1983; **53:**697-708.

106. Garzillo MJ, Garzillo TA. Does obesity cause low back pain? *J Manipulative Physiol Ther* 1994; **17:**601-04.

107. Genant HK, Cann CE, Faul DD. Quantitative computed tomography for assessing vertebral bone mineral. In: Dequeker J, Johnston CC, Jr (eds). *Non-invasive bone measurements: methodological problems*, pp215-49. Oxford: IRL Press, 1982.

108. German Society of Obesity Research (Deutche Gesellschaft für Adipositasforschung). Statement of the German Society of Obesity Research: guidelines for the treatment of obesity. *Adipositas* 1995; **9:**6-10.

109. Gibson RS. Principles of nutritional assessment. Oxford: Oxford University Press, 1990.

110. Giovannucci E, Ascherio A, Rimm EB, Coditz GA, Stampfer MJ, Willett WC. Physical activity, obesity, and risk for colon cancer and adenoma in men. *Ann Intern Med* 1995; **122:**327-34.

111. Goldstein DJ. Beneficial health effects of modest weight loss. *Int J Obes* 1992; **16:**397-415.

112. Gollnick PD, Armstrong RB, Saubert CW *et al.* Enzyme activity and fibre composition in skeletal muscle of untrained and trained men. *J Appl Physiol* 1972; **33:**312-19.

113. Gollnick PD, Armstrong RB, Saltin B, Sauber CW, Sembrowitsch WL, Shephard RE. Effect of training on enzyme activity and fiber composition of human skeletal muscle. *J Appl Physiol* 1973; **34:**107-11.

114. Gray DS, Bray GA, Gemayel N, Kaplan K. Effect of obesity on bioelectrical impedance. *Am J Clin Nutr* 1989; **50:**255-60.

115. Green JH, Muers MF. Comparisons between basal metabolic rate and diet induced thermogenesis in different types of chronic obstructive pulmonary disease. *Clin Sci* 1992; **83:**109-16.

116. Gregory J Foster K Tyler H, Wiseman M. *The dietary and nutritional survey of British adults.* Office of Population Consensus and Surveys. Social Survey Division. London: HMSO, 1990.

117. Griffin BA, Freeman DJ, Tait GW, Thomson J, Caslake MJ, Packard CJ, Shepherd J. Role of plasma triglyceride in the regulation of plasma low density lipoprotein (LDL) subfractions: relative contribution of small, dense LDL to coronary heart disease risk. *Atherosclerosis* 1994; **106**:241-253.

118. Grimby G, Broberg C, Krotkiewski K, Krotkiewski M. Muscle fibre composition in patients with spinal cord lesion. *Scand J Rehabil Med* 1976; **8:**37-42.

119. Grunstein R, Wilcox I, Yang TS, Gould Y, Hedner J. Snoring and sleep apnea in men: association with central obesity and hypertension. *Int J Obes* 1993; **17:**533-40.

120. Häggmark T, Jansson, Eriksson E. Fibre type area and metabolic potential of the thigh muscle in man after knee surgery and immobilization. *Int J Sports Med* 1981; **2:**12-17.

121. Hales CN, Barker DJP. Type 2 (non-insulin-dependent) diabetes mellitus: the thrifty phenotype hypothesis. *Diabetologia* 1992; **35:**595-601.

122. Hall TR, Young TB. A validation study of body fat distribution as determined by self-measurement of waist and hip circumferences. *Int J Obes* 1989; **13:**801-07.

123. Han TS. *Intra-uterine growth, body fat distribution and body composition in women.* MSc Thesis: University of Aberdeen, 1994.

124. Han TS, Lean MEJ. Body composition in patients with non-insulin-dependent diabetes and central fat distribution. *Diabetic Medicine* 1994; **11(suppl 1):**S39. [Abstr].

125. Han TS, McNeill G, Campbell DM. The relationship between women's birth weight and their current intra-abdominal fat mass. *Proc Nutr Soc* 1995a; **54:**182A. [Abstr].

126. Han TS, McNeill G, Baras P, Foster MA. Waist circumference predicts intra-abdominal fat better than waist:hip ratio in women. *Proc Nutr Soc* 1995b; **54:**152A. [Abstr].

127. Han TS, van Leer EM, Seidell JC, Lean MEJ. Waist circumference action levels predict cardiovascular risk factors: prevalence study in a random sample. *Br Med J* 1995c; **311:**1401-05.

128. Han TS, Lean MEJ. Lower leg length as an index of stature in adults. *Int J Obes* 1996; **20:**21-7.

129. Han TS, McNeill G, Campbell DM. The relationship between women's birth weight and their current cardiovascular function. *Proc Nutr Soc* 1996a; **55:**253A. [Abstr].

130. Han TS, Lean MEJ, Seidell JC. Waist circumference remains useful predictor of coronary heart disease. *Br Med J* 1996b; **312:**1227-28. [Lett].

131. Han TS, van Leer EM, Seidell JC, Lean MEJ. Waist circumference as a screening tool for cardiovascular risk factors: evaluation of receiver operator characteristics (ROC). *Obesity Research* 1996c; **4:**533-47.

132. Han TS, Richmond P, Avenell A, Lean MEJ. Waist circumference reduction and cardiovascular benefits during weight management in women. *Int J Obes* 1997a; **21:**127-34.

133. Han TS, McNeill G, Seidell JC, Lean MEJ. Predicting intra-abdominal fatness from anthropometric measures: the influence of stature. *Int J Obes* 1997b (in press).

134. Han TS, Seidell JC, Currall JEP, Morrison CE, Deurenberg P, Lean MEJ. The influence of height and age on waist circumference as an index of adiposity in adults. *Int J Obes* 1997c; **21**:83-89.

135. Han TS, Schouten JSAG, Lean MEJ, Seidell JC. The prevalence of low back pain and associations with body fatness, fat distribution and height. *Int J Obes* 1997d (in press).

136. Hanley JA, McNeill BJ. The meaning and use of the area under of receiver operating characteristic (ROC) curve. *Radiology* 1982; **143**:29-36.

137. Hanson P. Clinical exercise testing. In: Blair SN, Painter P, Pate RR, Smith LK, Taylor CB (eds). *Resource manual for guidelines for exercise testing and prescription*, pp205-22. Philadelphia: Lea & Febiger, 1988.

138. Harris MI, Klein R, Welborn TA, Kneiman MV. Onset of NIDDM occurs at least 4-7 yr before clinical diagnosis. *Diabetes Care* 1992; **15**:815-19.

139. Hartz AJ, Rupley DC, Rimm AA. Relationship of obesity to diabetes: influence of obesity level and body fat distribution. *Prev Med* 1983; **12**:351-57.

140. Hartz AJ, Rupley DC, Rimm AA. The association of girth measurements with disease in 32,856 women. *Am J Epidemiol* 1984; **119**:71-80.

141. Heady JA, Morris JN, Kagan A, Raffle PAB. Coronary heart disease in London busmen. A progress report with particular reference to physique. *Br J Prev Soc Med* 1961; **15**:143-53.

142. Health Education Authority. *Obesity and overweight*. London: HEA, 1991.

143. Health Education Board for Scotland. *Eating for health.* Edinburgh: Health Education Board for Scotland, 1997.

144. Heliövaara M. Body height, obesity, and risk of herniated lumbar intervertebral disc. *Spine* 1987; **12:**469-72.

145. Hellenius ML, de Faire U, Berglund B, Hamsten A, Krakau I. Diet and exercise are equally effective in reducing risk for cardiovascular disease. Results of a randomised controlled study in men with slightly to moderately raised cardiovascular risk factors. *Atherosclerosis* 1993; **103:**81-91.

146. Helmrich SP, Ragland DR, Leung RW, Paffenbarger RS. Physical activity and reduced occurrence of non-insulin-dependent diabetes mellitus. *N Engl J Med* 1991; **325:**147-52.

147. Henneman E, Somjen G, Carpenter D. Functional significance of cell size in spinal motor neurons. *J Neurophysiol* 1965; **28:**599-620.

148. Henriksson J, Reitman JS. Time course of changes in human skeletal muscle succinate dehydrogenase an cytochrome oxidase activities and maximal oxygen uptake with physical activity and inactivity. *Acta Physiol Scand* 1977; **99:**91-97.

149. Higgins M, Kannel W, Garrison R, Pinsky J, Stokes III J. Hazards of obesity - the Framingham experience. *Acta Med Scand* 1988; **723(suppl):**23-36.

150. Hill AJ, Silver EK. Fat friendless and unhealthy: 9-year old children's perception of body shape stereotypes. *Int J Obes* 1995; **19:**423-30.

151. Holmäng A, Björntorp P. The effects of cortisol on insulin sensitivity in muscle. *Acta Physiol Scand* 1992a; **144:**425-31.

152. Holmäng A, Larsson BM, Brezezinska Z, Björntorp P. The effects of short-term testosterone exposure on insulin sensitivity of muscles in female rats. *Am J Physiol* 1992b; **262:**E851-55.

153. Holmäng A, Brezezinska Z, Björntorp P. Effects of hyperinsulinemia on muscle fibre composition and capillarization in rats. *Diabetes* 1993; **42:**1073-81.

154. Holley J, Milic-Emili J, Becklake M, Bates D. Regional distribution of pulmonary ventilation and perfusion in obesity. *J Clin Invest* 1967; **46:**475-81.

155. Hom FG, Goodner CJ. Insulin dose-response characteristics among individual muscle and adipose tissues measured in the rat *in vivo* with ^{3}(H)2-deoxyglucose. *Diabetes* 1984; **33:**153-59.

156. Houmard JA, McCulley C, Roy LK, Bruner KR, McCammon MR, Israel RG. Effects of exercise training on absolute and relative measurements of regional adiposity. *Int J Obes* 1994; **18:**243-48.

157. Howald H. Training-induced morphological an functional changes in skeletal muscle. *Int J Sports Med* 1982; **3:**1-12.

158. Idler EL, Kasl SV, Lemke JH. Self-evaluated health and mortality among the elderly in New Haven, Connecticut, and Iowa and Washington Counties, Iowa, 1982-1986. *Am J Epidemiol* 1990; **131:**91-103.

159. Institute of Medicine. *Weighing the options. Criteria for evaluating weight management programs.* Thomas PR (ed). Institute of Medicine. Washington DC: National Academic Press, 1995.

160. Jackson AS, Pollock ML. Generalised equations for predicting body density of men. *Br J Nutr* 1978; **40:**497-504.

161. Jackson AS, Pollock ML, Ward A. Generalised equations for predicting body density of women. *Med Sci Sports Exerc* 1980; **12:**175-82.

162. James DE, Jenkins AS, Kraegen EW. Heterogeneity of insulin action in individual muscles in vivo. *Am J Phsyiol* 1985; **248:**E567-74.

163. Jarrett RJ, Fitzgerald AP. Height and glucose tolerance. *Diabetologia* 1992; **35:**191-92. [Lett].

164. Johnson D, Prud'homme D, Després J-P, Nadeau A, Tremblay A, Bouchard C. Relation of abdominal obesity to hyperinsulinaemia and high blood pressure in men. *Int J Obes* 1992; **16:**881-90.

165. Jones DA, Round JM. *Skeletal muscle in health and disease. A text book of muscle physiology*. Manchester: Manchester University Press, 1990.

166. Kahn HA, Sempos CT. *Statistical methods in epidemiology*. Oxford: Oxford University Press, 1989.

167. Kahn HS. Choosing an index for abdominal obesity: an opportunity for epidemiologic clarification. *J Clin Epidemiol* 1993; **46:**491-94.

168. Kannel WB, Cupples LA, Ramaswami R, Stokes J III, Kreger BE, Higgins M. Regional obesity and risk of cardiovascular disease; the Framingham study. *J Clin Epidemiol* 1991; **44:**183-90.

169. Kanaley JA, Andersen-Reid ML, Oenning L, Kottle BA, Jensen MD. Differential health benefits of weight loss in upper-body and lower-body obese women. *Am J Clin Nutr* 1993; **57**:20-6.

170. Kaplan GA, Camacho T. Perceived health and mortality: a nine-year follow-up of the human population laboratory cohort. *Am J Epidemiol* 1983; **117**:292-304.

171. Kaplan G, Barell V, Lusky A. Self rated state of health and survival in elderly adults. *J Gerontol Social Sci* 1988; **43**:S114-20.

172. Katch V. Assessment of body composition: comments on prediction. In: *Human body composition and fat distribution*. Norgan NG (ed). Wageningen: Stichting Netherlands Instituut voor de Voeding [distr], 1985 (Euro Nut report); **8**:15-30.

173. Katterman R, Jaworek D, Moller G. Multicenter study of a new enzymatic method of cholesterol determination. *J Clin Chem Clin Biochem* 1984; **22**:245-51.

174. Kelly IE, Han TS, Wallace AM, Walsh K, Lean MEJ. Body composition and serum leptin in non-insulin dependent diabetes. *Int J Obes* 1997 (in press).

175. Kelsey JL. An epidemiological study of acute herniated lumbar intervertebral discs. *Rheum Rehabil* 1975; **14**:144-59.

176. Kelsey JL, Githens PB, O'Conner T, Weil U, Calogero JA, Holford TR, *et al.* Acute prolapsed lumber intervertebral disc: an epidemiologic study with special reference to driving automobiles and cigarette smoking. *Spine* 1984; **9**:608-13.

177. Kempen KPG, Saris WHM, Westerterp KR. Energy balance during an 8-wk energy-restricted diet with and without exercise in obese women. *Am J Clin Nutr* 1995; **62**:722-29.

178. Khosla T, Lowe CR. Indices of obesity derived from body weight and height. *Br J Prev Soc Med* 1967; **21:**122-8.

179. Kissebah AH, Vydeligum N, Murray R *et al.* Relation of body fat distribution to metabolic complications of obesity. *J Clin Endocrinol Metab* 1982; **54:**254-260.

180. Kissebah AH, Peiris A, Evans DJ. Mechanisms associating body fat distribution with the abnormal metabolic profile in obesity. In: Berry EM, Blondheim SH, Eliahou HE, Shafrir E (eds). *Recent advances in obesity research V*, pp54-59. London: John Libbey, 1986.

181. Kleinbaum DG, Kupper LL, Morgenstern H. *Epidemiological research principles and quantitative methods*. California: Lifetime Learning, 1982.

182. Kline M. *Mathematics in Western Culture*. London: George Allen & Unwin, 1954.

183. Klissouras V. Heritability of adaptive variation. *J Appl Physiol* 1971; **31:**338-44.

184. Klissouras V, Pirnay F, Petit J. Adaptation to maximal effort: genetics and age. *J Appl Physiol* 1973; **35:**288-93.

185. Klissouras V. Prediction of athletic performance: genetic considerations. *Canad J Appl Sport Sci* 1976; **1:**195-200.

186. Knowler WC, Bennett PH, Hamman RF, Miller M. Diabetes incidence and prevalence in Pima Indians: a 19-fold greater incidence than in Rochester, Minnesota. *Am J Epidemiol* 1978; **108:**497-505.

187. Knowler WC, Pettitt DJ, Savage PJ, Bennett PH. Diabetes incidence in Pima Indians: contributions of obesity and parental diabetes. *Am J Epidemiol* 1981; **113:**144-45.

188. Kohrt WM, Kirwan JP, Staten MA, Bourey RE, King DS, Holloszy JO. Insulin resistance in aging is related to abdominal obesity. *Diabetes* 1993; **42:**273-81.

189. Komi PV, Vootasalo JHT, Havu M *et al.* Skeletal muscle fibres and muscle enzyme activities in monozygotic and dizygotic twins of both sexes. *Acta Physiol Scand* 1977; **100:**385-92.

190. Krotkiewski M, Seidell JC, Björntorp P. Glucose tolerance and hyperinsulinaemia in obese women: role of adipose tissue distribution, muscle fibre characteristics and androgens. *J Intern Med* 1990; **228:**385-92.

191. Kuczmarski RJ, Flegal KM, Campbell SM, Johnson CL. Increasing prevalence of overweight among US adults. The National Health and Nutrition Examination Surveys 1960-1991. *JAMA* 1994; **272:**205-11.

192. Kvist H, Chowdhury B, Grangård U, Tylen U, Sjöström L. Total and visceral adipose-tissue volumes derived from measurements with computed tomography in adults men and women. *Am J Clin Nutr* 1988; **48:**153-61.

193. Kvist H. Hallgren P, Jönsson L, Petterson P, Sjöberg C, Sjöström L, Björntorp P. Distribution of adipose tissue and muscle mass in alcoholic men. *Metabolism* 1993; **42:**569-73.

194. Lafontan M, Mauriege P, Galitzki J, Berlan M. Adrenergic regulation of regional adipocyte metabolism. In: Vague J, Björntorp P, Guy-Grand B, Rebuffé-Scrive,

Vague P (eds). *Metabolic Complications of Human Obesities*, pp161-72. Amsterdam: Elsevier, 1985.

195. Lapidus L, Bengtsson C, Larsson B, Pennert K, Rybo E, Sjöström L. Distribution of adipose tissue and risk of cardiovascular disease and death. 12 year follow-up of participants in the population study of women in Gothenburg, Sweden, *Br Med J* 1984; **289:**1261-63.

196. Larsson B, Svärdsudd K, Welin L, Wilhelmsen L, Björntorp P, Tibblin G. Abdominal adipose tissue distribution, obesity, and risk of cardiovascular disease and death: 13 year follow-up of participants in the study of men born in 1913. *Br Med J* 1984; **228:**1401-04.

197. LaRue A, Bank L, Jarvik L, Hetland M. Health in old age: how do physicians ratings and self ratings compare? *J Gerontol* 1979; **34:**687-91.

198. Launer LJ, Harris T, Rumpel C, Madans J. Body mass index, weight change, and risk of mobility disability in middle-aged and older women: the epidemiologic follow-up study of NHANES I. *JAMA* 1994; **271:**1093-98.

199. Law CM, Barker DJP, Osmond C, Fall CHD, Simmonds SJ. Early growth and abdominal fatness in adult life. *J Epidemiol Comm Health* 1992; **46:**184-86.

200. Law MR, Wald NJ, Wu T, Hackshaw A, Baily A. Systematic underestimation of associations between serum cholesterol concentration and ischemic heart disease in observation studies; data from the BUPA study. *Br Med J* 1994; **308:**363-6.

201. Lean MEJ. *Brown adipose tissue in humans*. MD Thesis: University of Cambridge, 1986.

202. Lean MEJ, Trayhurn P. Brown adipose tissue in humans. *Journal of Obesity and Weight Regulation* 1987; **6:**234-53.

203. Lean MEJ, Powrie JK, Anderson AS, Garthwaite PH. Obesity, weight loss and prognosis in type 2 diabetes. *Diabetic Medicine* 1990; **7:**228-33.

204. Lean MEJ, Mann JI. Obesity, body fat distribution and diet in the aetiology of non-insulin-dependent diabetes mellitus. In: Pickup J & Williams G (eds). *Textbook of diabetes*, pp181-91. Oxford: Blackwell Scientific Publications, 1991.

205. Lean MEJ, Han TS, Morrison CE. Waist circumference indicates the need for weight management. *Br Med J* 1995; **311:**158-61.

206. Lean MEJ, Han TS, Deurenberg P. Predicting body composition by densitometry from simple anthropometric measurements. *Am J Clin Nutr* 1996; **63:**4-14.

207. Lean MEJ, Han TS, Richmond P, Avenell A. Weight loss with high and low carbohydrate 1200 kcal diets. *Eur J Clin* 1997; **51:**243-48.

208. Lee J. Odds ratio or relative risk for cross-sectional data? *Int J Epidemiol* 1994; **23:**201-03.

209. Lemieux S, Prud'homme D, Nadeau A, Tremblay A, Bouchard C, Després J-P. Seven year changes in body fat and viscera adipose tissue in women. Associations with indexes of plasma glucose-insulin homeostasis. *Diabetes Care* 1996a; **19:**983-91.

210. Lemieux S, Prud'homme D, Bouchard C, Tremblay A, Després J-P. A single threshold value of waist girth identifies normal-weight and overweight subjects with excess visceral adipose tissue. *Am J Clin Nutr* 1996b; **64:**685-93.

211. Levy E, Levy P, Le Pen C, Basdevant A. The economic cost of obesity: the French situation. *Int J Obes* 1995; **19:**788-92.

212. Lew EA, Garfinkle L. Variations in mortality by weight among 750 000 men and women. *J Chron Dis* 1979; **32:**563-76.

213. Lillioja S, Young AA, Cutler CL, Ivy JL, Abbott WC, Zawadzki JK *et al*. Skeletal muscle capillary density and fibre type are possible determinants of *in vivo* insulin resistance in man. *J Clin Invest* 1987; **80:**415-24.

214. Lillioja S, Bogardus C. Insulin resistance in Pima Indians. *Acta Med Scand* 1988; **723 (suppl):**102-19.

215. Lissner L, Bengtsson C, Lapidus L, Bjorkelund C. Smoking initiation and cessation in relation to body fat distribution based on data from a study of Swedish women. *Am J Public Health* 1992; **82:**273-75.

216. Lithell H, Lingarde F, Hellsing K, Lundqvist G, Nygaard E, Vessby B, Saltin B. Body weight, skeletal muscle morphology, and enzyme activities in relation to fasting serum insulin concentration and glucose tolerance in 48-year-old men. *Diabetes* 1981; **30:**19-25.

217. Lopes-Virella MF, Stone P, Ellis S, Colwell JA. Cholesterol determination in high-density lipoproteins separated by three different methods. *Clin Chem* 1977; **23:**882-84.

218. Lucas A. Programming by early nutrition in man. In: Bock GR, Whelan J (eds). *The childhood environment and adult disease*, pp38-55. Chichister: John Wiley & Sons, 1991.

219. Luce J. Respiratory complications of obesity. *Chest* 1980; **78:**626-31.

220. Lukaski HC, Bolonchuk WW, Hall CB, Siders WA. Validation of tetrapolar bioelectrical impedance method to assess human body composition. *J Appl Physiol* 1986; **60:**1327-32.

221. Lumey LH, Stein AD, Ravelli AC. Maternal recall of birthweights of adult children: validation by hospital and well baby clinic records. *Int J Epidemiol* 1994; **23:**1006-12.

222. McCance RA. The effect of calorie deficiencies and protein deficiencies on final weight and stature. In: McCance RA, Widdowson EM (eds). *Calorie deficiencies and protein deficiencies*, pp319-28. London: Churchill, 1968.

223. McKeigue PM. Impaired glucose tolerance and height. *Br Med J* 1991; **303:**365. [Lett].

224. McNeill G, Fowler PA, Maughan RJ, McGaw BA, Fuller MF, Gvozdanovic D, Gvozdanovic S. Body fat in lean and overweight women estimated by six methods. *Br J Nutr* 1991; **65:**95-103.

225. Maddox GL, Douglass E. Self assessment of health: a longitudinal study of elderly subjects. *J Health Soc Behav* 1973; **14:**87-93.

226. Manson JE, Rimm EB, Stampfer MJ *et al*. Physical activity and incidence of non-insulin- dependent diabetes mellitus in women. *Lancet* 1991; **338:**774-78.

227. Manson JE, Willett WC, Stampfer MJ, Colditz DJ, Hunter DJ, Hankinson SE *et al*. Body weight and mortality among women. *New Engl J Med* 1995; **333:**677-85.

228. Mårin P, Andersson B, Krotkiewski M, Björntorp P. Muscle fibre composition and capillary density in women and men with NIDDM. *Diabetes Care* 1994; **17**:382-86.

229. Martorell R, Habicht J-P. Growth in early childhood in developing countries. In: Falkner F, Tanner JM. 1986, **Vol 3:**241-59.

230. Medical Outcomes Trust (2nd printing). *How to score SF-36 health survey.* Boston: Medical Outcomes Trust, 1994.

231. Mellin G. Correlations of spinal mobility with degree of chronic low back pain after correction for age and anthropometric factors. *Spine* 1987; **12:**464-68.

232. Mitchell RS, Filley GF. Chronic obstructive bronchopulmonary disease: I. Clinical feature. *Am Rev Resp Med* 1964; **89:**360-71.

233. Mooy JM, Grootenhuis PA, De Vries H, Valkenburg HA, Bouter LM, Kostense PJ, *et al.* Prevalence and determinants of glucose intolerance in Dutch Caucasian population. *Diabetes Care* 1995; **18:**1270-73.

234. Morris JK, Cook DG, Shaper AG. Non-employment and changes in smoking, drinking, and body weight. *Br Med J* 1992; **304:**536-41.

235. Morris JN, Heady JA, Raffle PAB, Roberts CG, Parks JW. Coronary heart disease and physical activity of work. Part I. *Lancet* 1953a; **ii:**1053-57.

236. Morris JN, Heady JA, Raffle PAB, Roberts CG, Parks JW. Coronary heart disease and physical activity of work. Part II. *Lancet* 1953b; **ii:**1112-20.

237. Morris JN, Heady JA, Raffle PAB. Physique of London busmen. Epidemiology of uniforms. *Lancet* 1956; **ii:**569-70.

238. Morris JN, Everitt MG, Pollard R, Chave SPW. Vigorous exercise in leisure-time: protection against coronary heart disease. *Lancet* 1980; **ii:**1207-10.

239. Morris JN, Clayton DG, Everitt MG, Semmence AM, Burgess EH. Exercise in leisure-time: coronary heart attack and death rates. *Br Heart J* 1990; **63:**325-34.

240. Morrison CE, Woodward M, Leslie W, Tunstall-Pedoe H. Effect of socioeconomic group of, management of, and survival after myocardial infarction and coronary death: analysis of community coronary event register. *Br Med J* 1997; **314:**541-46.

241. Mossey JM, Shapiro MA. Self-rated health: a predictor of mortality among the elderly. *Am J Public Health* 1982; **72:**800-08.

242. Moy CS, Songer TJ, LaPort RE, Doman JS, Kriska AM, Orchard TJ, Becker DJ, Drash AL. Insulin-dependent diabetes mellitus, physical activity, and death. *Am J Epidemiol* 1993; **137:**74-81.

243. Must A, Jaques PF, Dallal GE, Bajema CJ, Dietz WH. Long term morbidity and mortality of overweight adolescents: a follow-up of the Harvard growth study of 1922 to 1935. *N Engl J Med* 1992; **327:**1350-05.

244. Naimark A, Cherniak RM. Compliance of the respiratory system and its components in health and obesity. *J Appl Physiol* 1960; **15:**377-82.

245. Nakatsuka H, Satoh H, Watanabe T, Ida Y, Nishigouri M, Ikeda M. The reproducibility of reported height and body weight in repeated questionnaire surveys. *Int J Obes* 1995; **19:**50-56.

246. Norušis MJ. *Base System User's Guide, SPSS for Windows*: Release 6. SPSS inc., Chicago, Il 1993.

247. Office of Health Economics. *Obesity*. London: Office of Health Economics, 1994.

248. Ohlson LO, Larsson DC, Svärdsudd K Wellin L, Erikson H, Wilhelmsen L *et al.* The influence of body fat distribution on the incidence of diabetes mellitus - 13.5 years of follow-up of the participants in the study of men born in 1913. *Diabetes* 1985; **34:**1055-58.

249. Openbrier DR, Irwin MM, Rogers RM, Gottlieb GP, Dauber JH, van Thiel DH, Pennock BE. Nutritional status and lung function in patients with emphysema and chronic bronchitis. *Chest* 1983; **83:**17-22.

250. Paffenbarger RS, Laughlin ME, Gima AS, Black RA. Work activity of longshoremen as related to death from coronary heart disease and stroke. *N Engl J Med* 1970; **282:**1109-14.

251. Paffenbarger RS, Hyde RT, Wing AL, Hsieh C-C. Physical activity, all-cause mortality, and longevity of college alumni. *N Engl J Med* 1986; **314:**605-13.

252. Pate RR, Pratt M, Blair SN *et al.* Physical activity and public health: a recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *JAMA* 1995; **273:**402-07.

253. Pijls LTJ, Feskens EJM, Kromhout D. Self-rated, mortality, and chronic diseases in elderly men: the Zutphen study, 1985-1990. *Am J Epidemiol* 1993; **138:**840-48.

254. Pless CE, Pless IB. How will they remember. The accuracy of parent reports. *Arch Pediatr Adolesc Med* 1995; **149:**553-58.

255. Poehlman ET, Tremblay A, Després J-P, Fontaine E, Pérusse L, Thériault G, Bouchard C. Genotype-controlled changes in body composition and fat morphology following overfeeding in twins. *Am J Clin Nutr* 1986; **43:**723-31.

256. Popkess-Vawter S, Patzel B. Compounded problem: low back pain and overweight in adult females. *Orthop Nurs* 1992; **11:**31-35.

257. Pouliot M-C, Després JP, Lemieux SL Moorjani S, Bouchard C, Tremblay A, Nadeau A, Lupien PJ. Waist circumference and abdominal sagittal diameter: best simple anthropometric indexes of abdominal visceral adipose tissue accumulation and related cardiovascular risk in men and women. *Am J Cardiol* 1994; **73:**460-68.

258. Prentice AM. Alcohol and obesity. *Int J Obes* 1995; **19(suppl 5):**S44-S50.

259. Prentice AM, Jebb SA. Obesity in Britain: gluttony or sloth? *Br Med J* 1995; **311:**437-39.

260. Quetetlet LAJ. *Physique Sociale*. Brussels: C Musquardt, 1869; **Vol 2:**92.

261. Racette SB, Schoelloer DA, Kushner RF, Neil KM. Exercise enhances dietary compliance during moderate energy restriction in obese women. *Am J Clin Nutr* 1995; **62:**345-49.

262. Randle PJ, Garland PB, Hales CN, Newsholme EA. The glucose fatty-acid cycle: its role in insulin sensitivity and the metabolic disturbances of diabetes mellitus. *Lancet* 1963; **i**:785-89.

263. Randle PJ, Newsholme EA, Garland PB. Regulation of glucose uptake by muscle. 8. Effects of fatty acids, ketone bodies and pyruvate, and of alloxan-diabetes and starvation, on the uptake and metabolic fate of glucose in rat heart and diaphragm muscles. *Biochem J* 1964; **93**:652-65.

264. Rebuffé-Scrive M, Björntorp P. Regional adipose tissue metabolism in man. In: Vague J, Björntorp P, Guy-Grand B, Rebuffé-Scrive, Vague P, eds. *Metabolic Complications of Human Obesities*, pp149-59. Amsterdam: Elsevier 1985.

265. Rebuffé-Scrive M, Krotkiewski M, Elfverson J, Björntorp P. Muscle and adipose tissue morphology and metabolism in Cushing's syndrome. *J Clin Endocrinol Metab* 1988; **67**:1122-28.

266. Reeves SL, Varakamin C, Henry CJK. The relationship between arm-span measurement and height with special reference to gender and ethnicity. *Eur J Clin Nutr* 1996; **50**:398-400.

267. Reilly JJ, Murray LA, Durnin JVGA. Measuring the body composition of elderly subject: a comparison of methods. *Br J Nutr* 1994; **72**:33-44.

268. Reuss ML, Parer JI, Haris JL, Krueger TR. Haemodynamic effects of alpha-adrenergic blockade during hypoxia in fetal sheep. *Am J Obstet Gynecol* 1982; **142**:410-15.

269. Richelsen B, Pedersen SB. Association between different anthropometric measurements of fatness and metabolic risk parameters in non-obese, healthy, middle-aged men. *Int J Obes* 1995; **19:**169-74.

270. Richter EA, Garetto LP, Goodman MN, Ruderman NB. Enhanced muscle glucose metabolism after exercise: modulation by local factors. *Am J Physiol* 1984; **246:**E476-82.

271. Rimm EB, Stampfer MJ, Colditz GA, Chute GC, Litin LB, Willet WC. Validity of self-reported waist and hip circumferences in men and women. *Epidemiology* 1990; **1:**466-73.

272. Riquier D, Mory G, Bouillaud F, Thibault J, Wiessenbach J. Rapid increase of mitochondrial uncoupling protein and its mRNA in stimulated brown adipose tissue. *FEBS Lett* 1984; **178:**240-44.

273. Ross R. Léger L. Moris D, de Guise J, Guardo, R. Quantification of adipose tissue by MRI: relationship with anthropometric variables. *J Appl Physiol* 1992;**72:**787-95.

274. Ross R, Shaw KD, Martel Y, de Guise J, Avruch, L. Adipose tissue distribution measured by magnetic resonance imaging in obese women. *Am J Clin Nutr* 1993; **57:**470-75.

275. Roubenoff R, Wilson PWF. Advantage of knee height over height as an index of stature in expression of body composition in adults. *Am J Clin Nutr* 1993; **57:**609-13.

276. Royal College of Physicians. Obesity. A report of the Royal College of Physicians. *Journal of the Royal College of Physicians* 1983; **17:**6-65.

277. Salmons. S, Vrbová G. The influence of activity on some contractile characteristics of mammalian fast and slow muscles. *J Physiol* 1969; **201:**535-49.

278. Salmons S, Sréter FA. Significance of impulse activity in the transformation of skeletal muscle type. *Nature* 1976; **263:**30-34.

279. Salmons S, Henriksson J. The adaptive response of skeletal muscle to increased use. *Muscle and Nerve* 1981; **4:**94-105.

280. Saltin B, Blomqvist B, Mitchell JH *et al.* Response to exercise after bed rest and after training. *Circulation* 1968; **38:**1-77.

281. Saltin B, Gollnick PD. Skeletal Adaptability: significance for metabolism and performance, in: Peachey LD, Adrian RH, Geiger SR (eds). *Hand book of physiology: skeletal muscle*, p555. Baltimore, MD: Williams and Wilkins, 1983.

282. Sanders K. Coronary-artery disease and obesity. *Lancet* 1959; **ii:**432-35.

283. Schoeller DA, van Santen E, Paterson DW, Dietz W, Jaspan J, Klein PD. Total body water measurement in human with ^{18}O and ^{2}H labelled water. *Am J Clin Nutr* 1980; **33:**2686-93.

284. Schoenfeld DE, Malmrose LC, Blazer DG, Gold DT, Seeman TE. Self-rated health and mortality in the high-functioning elderly - a closer look at healthy individuals: MacArthur field study of successful aging. *J Gerotol* 1994; **49:**M109-15.

285. Schreiner PJ, Terry JG, Evans GW, Hinson WH, Crouse JR III, Heiss G. Sex-specific associations of magnetic resonance imaging-derived intra-abdominal and

subcutaneous fat areas with conventional anthropometric indices. *Am J Epidemiol* 1996; **144:**335-45.

286. Schuler G, Hambrecht R, Schlierf G, Niebauer J, Hauer KJ, *et al.* Regular physical exercise and low-fat diet: effect on progression of coronary artery disease. *Circulation* 1992; **86:**1-11.

287. Scottish Intercollegiate Guidelines Network. *Obesity in Scotland. Integrating prevention with weight management.* Edinburgh: Scottish Intercollegiate Guidelines Network, 1996.

288. Scottish Office. '*Scotland's health. A challenge to us all*'. Edinburgh: HMSO, 1992.

289. Secretary of State for Health. *The health of the nation. A consultative document for health in England.* London: HMSO, 1991.

290. Segal KR, Van Loan M, Fitzgerald PI, Hodgdon JA, Van Itallie TB. Lean body mass estimated by bioelectrical impedance analysis: a four site cross-validation study. *Am J Clin Nutr* 1988; **47:**7-14.

291. Seidell JC. *Overweight and fat distribution - associations with aspects of morbidity.* PhD Thesis: University of Wageningen, The Netherlands, 1986.

292. Seidell JC, Bakx KC, Deurenberg P, Burem J, Hautvast JGAJ, Huygen FJA. The relation between overweight and self rated health according to age, social class, slimming behavior and smoking habits in Dutch adults. *Am J Public Health* 1986a; **76:**1410-15.

293. Seidell JC, de Groot LCPGM, van Sonsbeek JLA, Deurenberg P, Hautvast JGAJ. Associations of moderate and severe overweight with self-reported illness and medical care in Dutch adults. *Am J Public Health* 1986b; **76**:264-69.

294. Seidell JC, Oosterlee A, Thijssen MAO, Burema J, Deurenberg P, Hautvast GAJ *et al.* Assessment of intra-abdominal and subcutaneous fat: relation between anthropometry and computed tomography. *Am J Clin Nutr* 1987; **45**:7-13.

295. Seidell JC, Oosterlee A, Deurenberg P, Hautvast JGAJ, Ruijs JHJ. Abdominal fat depots measured with computed tomography: effects of degree of obesity, sex, and age. *Eur J Clin Nutr* 1988; **42**:805-15.

296. Seidell JC, Björntorp P, Sjöström L, Sannerstedt R, Krotkiewski M, Kvist H. Regional distribution of muscle and fat mass in men - new insight into the risk of abdominal obesity using computed tomography. *Int J Obesity* 1989a; **13**:289-303.

297. Seidell JC, Hautvast JGAJ, Deurenberg P. Overweight: fat distribution and health risk. Epidemiological observations. *Infusionstherapie* 1989b; **16**:276-81.

298. Seidell JC. Environmental influences on regional fat distribution. *Int J Obes* 1991; **15**:31-5.

299. Seidell JC, Cigolini M, Charzewska J, Ellsinger B-M, Deslypere JP, Cruz A. Fat distribution in European men: a comparison of anthropometric measurements in relation to cardiovascular risk factors. *Int J Obes* 1992; **16**:17-22.

300. Seidell JC. Obesity in Europe - scaling and epidemic. *Int J Obes* 1995a; **19(suppl 3)**:S1-S4.

301. Seidell JC. The impact of obesity on health status: some implications for health care costs. *Int J Obes* 1995b; **19(suppl 6)**:S13-S16.

302. Seidell JC. Are abdominal diameters abominable indicators? In: Angel A, Bouchard C (eds). *Progress in obesity research*, pp303-06. London: John Libbey, 1995c.

303. Seidell JC, Han TS, Feskens EJM, Lean MEJ. Narrow hips and broad waist circumferences independently contribute to increased risk of NIDDM. *J Intern Med* 1997 (in press).

304. Sharp J, Henry J, Sweany S, Meadows W, Pietras R. The total work of breathing in normal and obese men. *J Clin Invest* 1964a; **43:**728-38.

305. Sharp J, Henry J, Sweany S, Meadows W, Pietras R. Effects of mass loading the respiratory system in man. *J Appl Physiol* 1964b; **19:**959-66.

306. Shephard RJ. *Body composition in biological anthropometry*. New York: Cambridge University Press, 1991.

307. Shimokata H, Muller DC, Andrés R. Studies in the distribution of body fat. *JAMA* 1989; **261:**1169-73.

308. Simoneau J-M, Bouchard C. Human variation in skeletal muscle fiber type proportion and enzyme activity. *Am J Physiol* 1989; **257:**E567-72.

309. Simopoulos AP, Van Itallie TB. Body weight, health and longevity. *Ann Intern Med* 1984; **100:**285-95.

310. Sjöström L, Narbo K, Sjöström D. Costs and benefits when treating obesity. *Int J Obes* 1996; **19 (suppl 6):**S9-S12.

311. Siri WE. Body composition from fluid spaces and density analysis of methods. In: Brozeck J, Henschel A (eds). *Techniques For Measuring Body Composition,* pp223-44. Washington DC: National Academy of Sciences/National Research Council, 1961.

312. Smit HA, Verschuren WMM, Bueno de Mesquitoa HB, Seidell JC. *Monitoring van risicofactoren en gezondheid in Nederland (MORGEN-project): doelstellingen en werkwije.* Raaportnummer 263200001, februari 1994.

313. Smith U. Obesity and insulin resistance - potential importance of adipose tissue metabolism. In: Vague J, Björntorp P, Guy-Grand B, Rebuffé-Scrive, Vague P, eds. *Metabolic Complications of Human Obesities*, pp173-78. Amsterdam: Elsevier, 1985.

314. Sobal J, Nicolopoulos V, Lee J. Attitudes about overweight and dating among secondary school students. *Int J Obes* 1995; **19:**376-81.

315. Sohlström A, Wahlund L-O, Forsum E. Adipose tissue distribution as assessed by resonance imaging and total body fat by magnetic resonance imaging, underwater weighing, and body-water dilution in healthy women. *Am J Clin Nutr* 1993; **58:**830-38.

316. Sönnichsen AC, Richter WO, Schwandt P. Benefit from hypocaloric diet in obese men depends on the extent of weight loss regarding cholesterol, and on a simultaneous change in body fat distribution regarding insulin sensitivity and glucose tolerance. *Metabolism* 1992; **41:**1035-40.

317. Sréter FA, Elzinger M, Salmons S *et al.* The Nτ-methylhistodine content of myosin in stimulated and cross-innervated skeletal muscles of the rabbits. *FEBS Lett* 1975; **57:**107-11.

318. Staffieri JR. A study of social stereotype of body image in children. *J Pers Soc Psychol* 1978; **7:**101-04.

319. Steele RH, Heard BE. Size of the diaphragm in chronic bronchitis. *Thorax* 1973; **28:**55-60.

320. Stewart AL, Brook RH. Effects of being overweight. *Am J Public Health* 1983; **73:**171-78.

321. Stewart AL, Hays, RD, Wells KB, Rogers WH, Spritzer KL, Greenfield S. Long-term functioning and well-being outcomes associated with physical activity and exercise in patients with chronic conditions in the medical outcomes study. *J Clin Epidemiol* 1994; **47:**719-30.

322. Stunkard AJ, Sorensen TIA, Hanis C, Teasdale YW, Chakraborty R, Schull WJ, Schulsinger F. An adoption study of human obesity. *New Engl J Med* 1986; **314:**193-98.

323. Stunkard AJ, Harris JR, Pedersen NL, McClearn GE. The BMI of twins who have been reared apart. *N Engl J Med* 1990; **322:**1483-87.

324. Stunkard AJ. Current views on obesity. *Am J Med* 1996; **100:**230-36.

325. Sturmans F. *Epidemiology: Theorie, Methoden en Toepassing.* Nijmegen: Dekker & van de Vegt, 1984.

326. Sullivan M, Karlsson J, Sjöström L, Backman L, Bengtsson C, Bouchard C *et al.* Swedish obese subjects (SOS) - an intervention study of obesity. Baseline evaluation of health psychosocial functioning in the first 1743 subjects examined. *Int J Obes* 1993; **17:**503-12.

327. Surratt PM, McTier RF, Findley LJ, Pohl SL, Wilhoit SC. Effect of very-low-calorie diets with weight loss on obstructive sleep apnea. *Am J Clin Nutr* 1992; **56:**182S-84S.

328. Suzuki S, Yamamuro T. Long-term effects of estrogen on rat skeletal muscle. *Exper Neurol* 1985; **87:**291-99.

329. Swai AB, Kitange H, Masuki G, Kilima PM, Alberti KGMM, McLarty DG. Is diabetes mellitus related to undernutrition in rural Tanzania? *Br Med J* 1992; **305:**1057-62.

330. Swinscow TDV. *Statistics at square one.* London: British Medical Association, 1983.

331. Tanner JM, Whitehouse RH, Hughes PCR, Vince FP. Effect of human growth hormone treatment for 1 to 7 years on growth of 100 children, with growth hormone deficiency, low birth weight, inherited smallness, Turner's syndrome, and other complaints. *Arch Dis Childh* 1971; **46:**745-82.

332. Tanner JM, Hayashi T, Preece MA, Cameron N. Increase in length of leg relative to trunk in Japanese children and adults from 1057 to 1977: comparison with British and with Japanese Americans. *Ann Hum Biol* 1982; **9:**411-23.

333. Tanner JM. *Foetus into man: physical growth from conception to maturity.* London: Castlemead Publishing, 1989.

334. Thorstensson A, Sjodin B, Karlsson J. Enzyme activities and muscle strength after "sprint training" in man. *Acta Physiol Scand* 1975; **94:**313-18.

335. Thurlbeck WM. Diaphragm and body weight in emphysema. *Thorax* 1978; **33:**483-87.

336. Treuth MS, Hunter GR, Kekes-Szabo T. Estimating intraabdominal adipose tissue in women by dual X-ray absorptiometry. *Am J Clin Nutr* 1995; **62:**527-32.

337. Troisi RJ, Heinold JW, Vokonas PS, Weiss ST. Cigarette smoking, dietary intake, and physical activity: effects on body fat distribution - the normative aging study. *Am J Clin Nutr* 1991; **53:**1104-11.

338. Troy LM, Michels KB, Hunter DJ, Spiegelman D, Manson JE, Colditz GA *et al.* Self-reported birthweight and history of having been breastfed among younger women: an assessment of validity. *Int J Epidemiol* 1996; **25:**122-27.

339. UK Prospective Diabetes study Group. UK Prospective Diabetes Study 6. Complications in newly diagnosed type 2 diabetic patients and their association with different clinical and biochemical risk factors. *Diabetes Res* 1990; **13:**1-11.

340. US Department of Agriculture and US Department of Health and Human Services. *Dietary guidelines for Americans* (3rd edn). Washington, DC: Publication GPO-273-930, 1990.

341. Vague J. La differenciation sexuelle, facteur déterminant des formes de l'obésité. *Presse Med* 1947; **53:**339.

342. Vague J. Le diabète de la femme androide. *Presse Med* 1949; **57:**835.

343. Vague J. The degree of masculine differentiation of obesity - factor determining predisposition to diabetes, atherosclerosis, gout and uric calculus. *Am J Clin Nutr* 1956; **4:**20-34.

344. Valdez R. A simple model-based index of abdominal adiposity. *J Clin Epidemiol* 1991; **44:**955-56.

345. Vandenbergh E, van de Woestijne KP, Gyselen A. Weight changes in the terminal stages of chronic obstructive pulmonary disease. *Am Rev Respir Dis* 1967; **95:**556-66.

346. Van der Kooy K, Leenen R, Seidell JC, Deurenberg P, Hautvast JG. Effect of a weight cycle on visceral fat accumulation. *Am J Clin Nutr* 1993; **58:**853-57.

347. Van der Zee KI, Sanderman R. *Het meten van de algemene gezondheidstoestand met de RAND-36: een handleiding.* Groningen: Noordelijk Centrum voor Gezondheidsvraagstukken, NCG, 1995.

348. Van Gaal LF. *Body fat distribution: endocrine, metabolic and therapeutic aspects related to atherosclerosis.* PhD Thesis: Universiteit Antwerpen, Antwerp, Belgium, 1990.

349. Van Leer EM, van Noord PAH, Seidell JC. Components of adult height and height loss: secular trend and effects of aging in women in the DOM project. *Ann Epidemiol* 1992; **2:**611-15.

350. Verschuren WMM. *Blood cholesterol - a public health perspective.* PhD Thesis: Landbouwuniversiteit Wageningen, The Netherlands, 1995.

351. Vrbová G. Changes in the motor reflexes produced by tenotomy. *J Physiol* 1963; **192:**39-40.

352. Waaler HT. Height, weight and mortality. The Norwegian experience. *Acta Med Scand Supplement* 1984; **679:**1-56.

353. Wadden TA, Steen SN, Wingate BJ, Foster GD. Psychosocial consequences of weight reduction: how much weight loss is enough? *Am J Clin Nutr* 1996; **63 (suppl):**461S-5S.

354. Wade AJ, Marbut MM, Round JM. Muscle fibre type and aetiology of obesity. *Lancet* 1990; **335:**805-08.

355. Walker L. Going down? *Balance* 1997; (issue 156, March/April), pp41-45.

356. Watt T, Dodd F, Keegan M, Campbell IT. Accuracy and precision of techniques used for measuring height in critically illness. *Proc Nutr Soc* 1994; **53:** A67. [Abstr].

357. Weidner MD, Gavigan KE, Tyndall GL, Hickey MS, McCammon MR, Houmard JA. Which anthropometric indices of regional adiposity are related to insulin resistance of aging. *Int J Obes* 1995; **19:**325-330.

358. Wellens RI, Roche AF, Khamis HJ, Jackson AS, Pollock ML, Siervogel RM. Relationships between body mass index and body composition. *Obesity Research* 1996; **4:**35-44.

359. Wells N. *Back pain.* London: Office of Health Economics, 1985.

360. Wilcox I, Collins FL, Grunstein RR, Hedner J, Kelly DT, Sullivan CE. Relationship between chemosensitivity, obesity and blood pressure in obstructive sleep apnea. *Blood Press* 1994; **3:**47-54.

361. Williams DRR, Byrn C, Clark PMS, Cox L, Day NE, Tauman G, Wang T, Hale CN. Raised proinsulin concentration as early indicator of β cell dysfunction. *Br Med J* 1991; **303:**95-96.

362. Williamson DF, Pamuk E, Thun M, Flanders D, Byers T, Heath C. Prospective of intentional weight loss and mortality in never-smoking overweight US white women aged 40-64 years. *Am J Epidemiol* 1995; **141:**1128-41.

363. Wilmore JH, Vodak PA, Parr RB, Girandola RN, Billing JE. Further simplification of a method for determination of residual lung volume. *Med Sci Sports Exerc* 1980; **12:**216-18.

364. Wilson DO, Rogers RM, Wright EC, Anthonisen NR. Body weight in chronic obstructive pulmonary disease: the National Institutes of Health Intermittent Positive Pressure Breathing Trial. *Am Rev Respir Dis* 1989; **139:**1435-38.

365. Wing RR, Jefferey RW, Burton LR, Kuller LH, Thorson C, Folsom AR. Change in waist-hip ratio with weight loss and its association with change in cardiovascular risk factors. *Am J Clin Nutr* 1992; **55:**1086-92.

366. Wing RR, Jefferey RW. Effect of modest weight loss on changes in cardiovascular risk factors: are there difference between men and women or between weight loss and maintenance? *Int J Obes* 1995; **19:**67-73.

367. Wolf AM, Colditz GA. Social economic effects of body weight in the United States. *Am J Clin Nutr* 1996; **63(suppl):**466S-69S.

368. Womersley J. *Obesity: its assessment, significance and control*. PhD Thesis: University of Glasgow, 1974.

369. Wood PD. Impact of experimental manipulation of energy intake and expenditure on body composition. *Crit Rev Food Sci Nutr* 1993; **33**:369-73.

370. World Health Organization Study Group on Diabetes Mellitus. Diabetes mellitus. World Health Organization Tech Rep Ser 1985; **727**:1-113.

371. World Health Organization. Geographical variation in the major risk factors of coronary heart disease in men and women aged 35-64 years. The MONICA Project. *World Health Stat Q* 1988; **41**:115-40.

372. World Health Organisation. *Measuring obesity - classification and description of anthropometric data. Report on a WHO consultation on the epidemiology of obesity*. Copenhagen: WHO Regional Office for Europe, 1989. [EUR/ICP/NUT 125, 0612v.]

373. World Health Organisation. *Expert Committee on Physical Status: The use and interpretation of anthropometry: report of a WHO expert committee*. Geneva: World Health Organization Tech Rep Ser, 1995.

374. Wright D, Barrow S, Fisher AD, Horsley SD, Jayson MI. Influence of physical, psychological and behavioural factors on consultation for back pain. *Br J Rheumatol* 1995; **34**:156-61.

375. Yamanouchi K, Shinozaki T, Chikada K, Nishikawa T, Ito K, Shimizu S, *et al*. Daily walking combined with diet therapy is a useful means of obese NIDDM

patients not only to reduce body weight but also to improve insulin sensitivity. *Diabetes Care* 1995; **18:**775-78.

376. Young TK, Gelskey DE. Is noncentral obesity metabolically benign? *JAMA* 1995; **274:** 1939-41.

377. Yudkin JS. How can we best prolong life? Benefits of coronary risk factor reduction - non-diabetic and diabetic subjects. *Br Med J* 1993; **306:**1313-18.

378. Zaadstra BM, Seidell JC, Van Noord PAH, te Velde ER, Habbema JDF, Vrieswijk B, Karbaat J. Fat and female fecundity: prospective study of effect of body fat distribution on conception rates. *Br Med J* 1993; **306:**484-87.

379. Zerah F, Harf A, Perlemuter L, Lorina J, Lorino AM, Atlan G. Effects of obesity on respiratory resistance. *Chest* 1993; **103:**1470-76.

380. Zhang Y, Proenca R, Maffei M, Barone M, Leopold L, Friedman JM. Positional cloning of the mouse obese gene and its human homologue. *Nature* 1994; **372:**425-32.

PUBLICATIONS ARISING FROM THE PRESENT THESIS

Peer reviewed original papers published or in press

1. Lean MEJ, **Han TS**, Morrison CE. Waist circumference as a measure for indicating need for weight management. *British Medical Journal* 1995; **311:**158-161.

2. **Han TS**, van Leer EM, Seidell JC, Lean MEJ. Waist circumference action levels in the identification of cardiovascular risk factors: prevalence study in a random sample. *British Medical Journal* 1995; **311:**1041-45.

3. **Han TS**, Lean MEJ. Lower leg length as an index of stature in adults. *International Journal of Obesity* 1996; **20:**21-27.

4. Lean MEJ, **Han TS**, Deurenberg P. Predicting body composition by body density from simple anthropometric measurements. *American Journal of Clinical Nutrition* 1996; **63:**4-14.

5. **Han TS**, Carter R, Currall JEP, Lean MEJ. The influence of fat free mass on prediction of densitometric body composition by bioelectrical impedance analysis and by anthropometry. *European Journal of Clinical Nutrition* 1996; **50:**542-48.

6. **Han TS**, van Leer EM, Seidell JC, Lean MEJ. Waist circumference as a screening tool for cardiovascular risk factors: evaluation of receiver operating characteristics (ROC). *Obesity Research* 1996; **4:**533-47.

7. **Han TS**, Seidell JC, Currall JEP, Morrison CE, Deurenberg P, Lean MEJ. The influences of height and age on waist circumference as an index of adiposity in adults. *International Journal of Obesity* 1997; **21:**83-89.

8. **Han TS**, Richmond P, Avenell A, Lean MEJ. Waist circumference reduction and cardiovascular benefits during weight management in women. *International Journal of Obesity* 1997; **21:**127-34.

9. **Han TS**, McNeill G, Seidell JC, Lean MEJ. Predicting intra-abdominal fatness from anthropometric measures: the influence of stature. *International Journal of Obesity* 1997 (in press).

10. **Han TS**, Schouten JSAG, Lean MEJ, Seidell JC. The prevalence of low back pain and associations with body fatness, fat distribution and height. *International Journal of Obesity* 1997 (in press).

11. Seidell JC, **Han TS**, Feskens EJM, Lean MEJ. Narrow hips and broad waist circumferences independently contribute to increased risk of NIDDM. *Journal of Internal Medicine* 1997 (in press).

Peer reviewed original papers submitted

12. **Han TS**, Tijhuis MAR, Lean MEJ, Seidell JC. Quality of life in relation to overweight and body fat distribution.

13. **Han TS**, Smit HA, Lean MEJ, Seidell JC. Symptoms of respiratory insufficiency in relation to body fat and fat distribution.

14. **Han TS**, Feskens EJM, Lean MEJ, Seidell JC. Associations of stature, body mass and fat distribution with non-insulin dependent diabetes mellitus.

15. **Han TS**, Bijnen FCH, Lean MEJ, Seidell JC. Separate associations of waist and hip circumference with lifestyle factors.

16. Lean MEJ, **Han TS**. Natural sporting ability, birth weight and predisposition to cardiovascular disorders.

17. Lean MEJ, **Han TS**, Seidell JC. Impairment of health and quality of life in the overweight according to standard cut-offs of body mass index.

18. **Han TS**, Lean MEJ, Seidell JC. Impairment of health and quality of life from abdominal fat accumulation, using waist circumference Action Levels.

19. **Han TS**, Morrison CE, Lean MEJ. Skeletal proportions and metabolic disorders in adults.

20. **Han TS**, Kelly IE, Walsh K, Greene R, Lean MEJ. Relationship between volumes and areas from single transverse scans of intra-abdominal fat by magnetic resonance imaging.

21. **Han TS**, Morrison CE, Lean MEJ. 'Waist Watcher' tape measure as a screening tool to identify people at increased health risk through intra-abdominal fat accumulation.

Letters

22. **Han TS**, Lean MEJ, Seidell JC. Waist circumference remains useful predictor of coronary heart disease. *British Medical Journal* 1996; **312:**1227-28 [Lett].

Published abstracts from presentation at scientific meetings

1. **Han TS**, Lean MEJ. Body composition estimation when height is unavailable. *Proceedings of the Nutrition Society* 1994; **53:**102A.

2. **Han TS**, Richmond P, Currall JEP, Lean MEJ. Waist circumference reflects changes in cardiovascular risk factors in women during weight loss. *International Journal of Obesity* 1995; **19(suppl 2):**95.

3. **Han TS**, van Leer EM, Seidell JC, Lean MEJ. Waist circumference identifies cardiovascular risk factors. *Proceedings of the Nutrition Society* 1995; **54:**172A.

4. **Han TS**, Morrison CE, Lean MEJ. Waist circumference indicates the need for weight management. *Proceedings of the Nutrition Society* 1995; **54:**180A.

5. **Han TS**, Deurenberg P, Lean MEJ. Predicting body composition in adults. *Proceedings of the Nutrition Society* 1996; **55:**85A.

6. **Han TS**, Richmond P, Lean MEJ. Benefits of waist reduction and its use as guideline for weight management in women. *FASEB Journal* 1996; **10:**1207.

7. **Han TS**, Richmond P, Lean MEJ. Weight management in women using 1200 kcal diets of high and low carbohydrate. *International Journal of Obesity* 1996; **20(suppl 4):**48.

8. **Han TS**, Smit HA, Lean MEJ, Seidell JC. Respiratory symptoms in relation to body mass and fat distribution. *International Journal of Obesity* 1997; (in press).

9. **<u>Han TS</u>**, Tijhuis MAR, Lean MEJ, Seidell JC. Quality of life in relation to overweight and body fat distribution. *International Journal of Obesity* 1997; (in press).

10. **<u>Han TS</u>**, Bijnen FCH, Lean MEJ, Seidell JC. Separate associations of waist and hip circumference with lifestyle factors. *International Journal of Obesity* 1997; (in press).

11. **<u>Han TS</u>**, Hooper JP, Morrison CE, Lean MEJ. Associations of skeletal proportions with metabolic disorders in adults. *Proceedings of the Nutrition Society* 1997; (in press).

12. Kelly IE, **<u>Han TS</u>**, Wallace AM, Walsh K, Lean MEJ. Body composition and serum leptin in non-insulin diabetes. *International Journal of Obesity* 1997; (in press).

13. **<u>Han TS</u>**, Lean MEJ. Natural sporting ability, birth weight and predisposition to cardiovascular disorders: study of British former soldiers. *Proceedings of the Nutrition Society* 1997; (in press).